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Sources of Atmospheric Cadmium

Energy and Environmental Analysis, Inc, Arlington, VA

Prepared for

Environmental Protection Agency, Research Triangle Park, NC Office of Air Quality Planning and Standards

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This report is one of a series of reports which will be used by EPA in responding to the Congressional request under section 122 of the Clean Air Act Amendments of 1977 to determine whether atmospheric emissions of cadmium pose any threat to public health. This report surveys the uses of cadmium and potential emission sources to determine which sources are the most significant both in terms of total emissions and potential ambient levels.

It is estimated that about 850 tons of cadmium were emitted during 1974, with the largest estimated emitted of cadmium being the production of zinc. Other sources identified were incinerators, iron and steel mills, fossil fuel combustion, smelters.

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The conclusions presented in the study are, of course, solely the responsibility of Energy and Environmental Analysis, Inc.

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EXECUTIVE SUMMARY

This report is one of a series of reports which will be used by EPA in responding to the Congressional request under section 122 of the Clean Air Act Amendments of 1977 to determine whether atmospheric emissions of cadmium pose any threat to public health. This report surveys the uses of cadmium and potential emission sources to determine which sources are the most significant both in terms of total emissions and potential ambient levels.

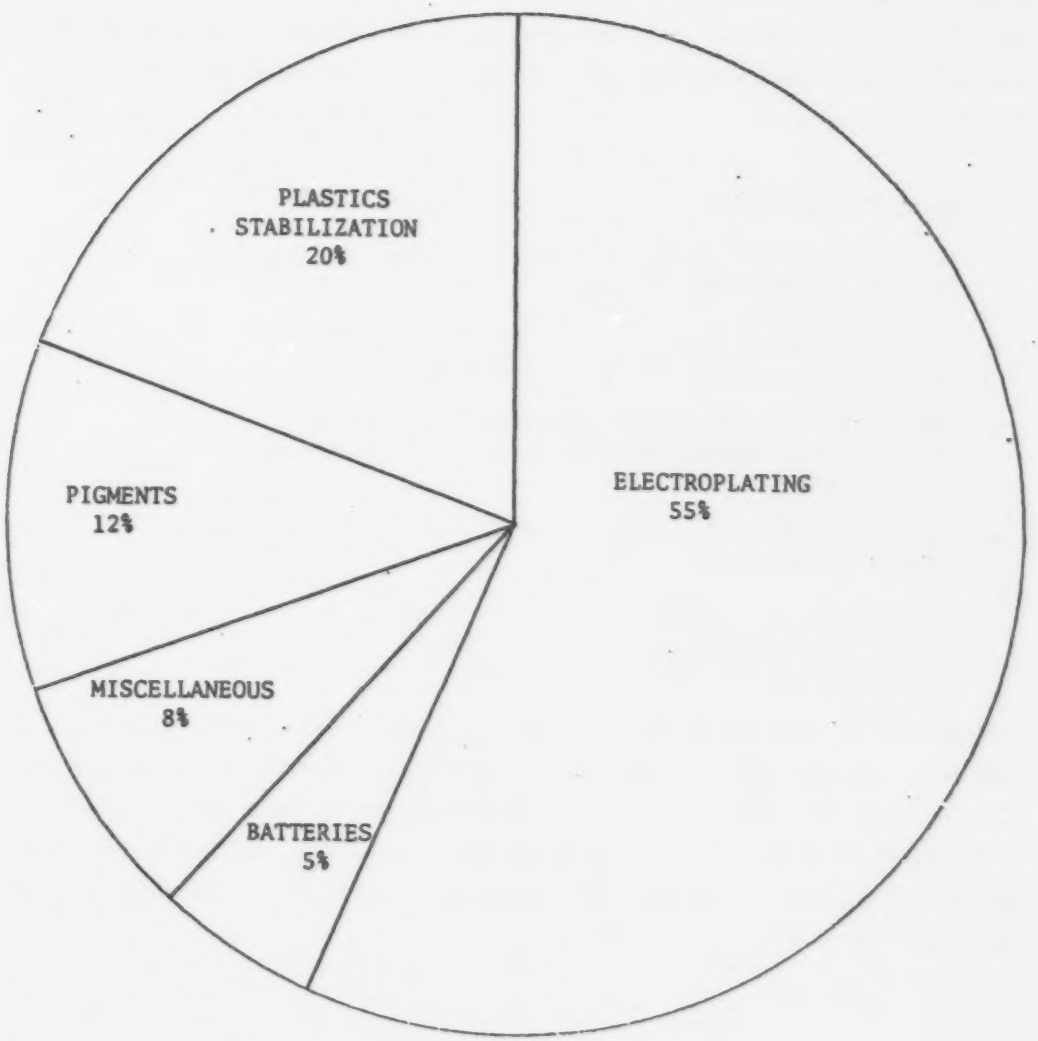
The basic methodology used in this report is as follows:

- Determination of potential cadmium emission sources through a literature review;
- Determination of emission factors (lbs. cadmium emitted/unit output) for each source;
- Application of these emission factors to current and projected production levels to obtain estimates of total cadmium emissions;
- Evaluation of control technology for reducing cadmium emissions;
- Screening of all cadmium sources to identify those sources potentially able to cause measurable ambient levels of cadmium.

Consumption of cadmium in the U.S. has averaged about 5,000 megagrams/year over the last several years. United States production is closely tied to zinc production and has not been adequate to meet demand. In 1975 almost 40 percent of the cadmium used in the U.S. was imported. The principal uses of cadmium and their relative share of consumption is shown in Figure E-1.

FIGURE E-1

1975 CADMIUM CONSUMPTION IN THE UNITED STATES(1)



It is estimated that about 850 tons of cadmium were emitted during 1974. The breakdown of emissions by source category is shown on Table E-1. This table also lists the anticipated change in cadmium emissions due to growth changes in technology or the anticipated imposition of higher efficiency control equipment.

As Table E-1 shows, the largest estimated emitter of cadmium is the production of zinc. This source accounts for approximately 53 percent of total cadmium emissions. Although zinc production is expected to increase significantly, emissions are not expected to increase and very possibly will decrease due to the increased use of electrolytic processes which have almost no emissions.

Emissions from other major sources (incinerators, iron and steel and fossil fuel combustion) are expected to remain relatively constant as the increased production is balanced by the increasing levels of control technology.

Data on Table E-2 is based on the use of "best judgement" emission factors developed through a review of the literature and various stack test results. Table E-2 shows the emission factors developed in this study. Also shown on Table E-2 is the minimum and maximum emission factor reported for any of the sources. It is clear that significant differences can exist among tests on different sources. As such, although the emission factors are probably adequate for the purpose of evaluating differences among source categories, care must be taken in the application of these factors to any particular source.

After emission factors and emission levels were determined for particular source categories, sources were evaluated to determine if an individual source had the potential to cause a measurable level of cadmium (assumed to be 0.1 ng/m^3 on an annual average). Screening was

TABLE E-1

AIRBORNE CADMIUM EMISSIONS--1974, 1985

Source	Production 1974*	Emissions Estimate		Reference**	Production 1985(e)	Emissions Estimate	Reference**
MINING							
Zinc	478,850	<1		12	845,377	<1	41
Copper	1,414,246.8	<1		12	2,563,122	<1	41
Lead	603,024	<1		12	1,169,524	<1	41
PRIMARY METALS							
Zinc							
Pyrometallurgic	423,000	529		40	1,000,000	529	9
Electrolytic	121,945	0		40	-	-	-
Lead	866,095	2		40	790,000	2	9
Copper	1,435,662.4	5		40	3,849,844	13	9
Cadmium	3,088.2	2		12	1,139	1	9
SECONDARY METAL PROCESSING							
Iron and Steel							
Sinter Windbox Uncontrolled	21.94×10^6	22		13	-	-	
Sinter Windbox w/Rotoclone and ESP	11.35×10^6	5		13	40×10^6	2-19	13
Basic Oxygen Furnace Uncontrolled	1.2×10^6	<1		13	-	-	
BOF w/Venturi or ESP	78.8×10^6	<1		13	116.7×10^6	1	13
Open Hearth Uncontrolled	7.64×10^6	22		13	-	-	
Open Hearth w/ESP	29.06×10^6	2		13	21.1×10^6	1	13
Electric Arc Controlled	27.3×10^6	5		13	38.8×10^6	7	13
Blast Furnace Controlled	95.2×10	0		13	113.6×10^6	0	13
Zinc	75,409	<1		47	130,000	1	47
Lead	698,698	<1		12	860,000	<1	9
Copper	513,308	38		12	800,000	60	20
MANUFACTURING							
Pigments	1,212.1	9		6	1,560	12	6
Stabilizers	991.8	3		6	1,179	4	6
Batteries	628.14	1		6	2,200	2	6
FOSSIL FUEL COMBUSTION							
Coal-Fired Power Plants	3.913×10^8	12		42	530.750×10^6	16	24
Oil-Fired Power Plants	500×10^6 (barrels)	9		42	732.2×10^6 (barrels)	14	46
Heating Oil	935.1×10^6 (barrels)	29	(1975)	45	980.9×10^6 (barrels)	31	46
Diesel Oil	11×10^9 (gallons)	4		39	15.12×10^9 (gallons)	5	38
Gasoline	$1,330,074 \times 10^6$ (VMT)	13		43	$1,707,152 \times 10^6$ (VMT)	17	44
MISCELLANEOUS							
Motor Oil	$1,028,121 \times 10^6$ (VMT)	1		43	$1,707,152 \times 10^6$ (VMT)	2	44
Rubber Tire Wear	$1,330,024 \times 10^6$ (VMT)	5		43	$1,707,152 \times 10^6$ (VMT)		44
Fungicides	59,800	<1		9	92,769	<1	9
Fertilizers	$8,535 \times 10^3$	<1		9	13,758	1	9
Cement	$81,210 \times 10^3$	<1		9	$94,537 \times 10^3$	<1	32
INCINERATION							
Sewage Sludge Incinerators	1,460,000	<1		36	1,551,250	<1	35,36
Municipal Incinerators	20,143,620	131		34	20,143,620	131	34
		850				877	

* tons per year unless otherwise stated.

e = estimated

VMT = vehicle miles traveled

** Reference refers to production

TABLE E-2

CADMIUM EMISSION FACTORS

SOURCE	MINIMUM	MAXIMUM	BEST JUDGEMENT	REFERENCES
PRIMARY METALS PROCESSING				
ZINC				
Coking	$1.96^{lb}/_{TZnThru}$ (EST,MB)	$2.48^{lb}/_{TZnThru}$ (STK,AA)	$2.24^{lb}/_{TZnThru}$	4,5
Sintering w/Cyclone	$4.06^{lb}/_{TZnThru}$ (STK,AA)	$8.58^{lb}/_{TZnThru}$ (STK,AA)	$6.32^{lb}/_{TZnThru}$ (STK,AA)	5
Sintering w/Cyclone & ESP	$2.10^{lb}/_{TZnThru}$ (STK,AA)	$2.22^{lb}/_{TZnThru}$ (STK,AA)	$2.16^{lb}/_{TZnThru}$ (STK,AA)	5
Roasting			~0 (EST)	6
Horizontal Retort	$1.2x10^{-2}{}^{lb}/_{TZnThru}$ (EST)	$8.7x10^{-2}{}^{lb}/_{TZnThru}$ (STK,AA)	$6x10^{-3}{}^{lb}/_{TZnProd}$ (EST)	6
Vertical Retort			$6.5x10^{-2}{}^{lb}/_{TZnThru}$ (STK,AA)	5,6
Electrothermic	$1.43^{lb}/_{TZnProd}$ (EST)	$2.96^{lb}/_{TZnProd}$ (STK,AA)	$1.2x10^{-2}{}^{lb}/_{TZnProd}$ (EST)	6
Overall (Not Electrolytic)			$2.5^{lb}/_{TZnProd}$	5,7,8
Electrolytic			~0	6
LEAD				
Overall Smelter	$5.2x10^{-2}{}^{lb}/_{TPbProd}$ (EST,MB)	$2.6x10^{-1}{}^{lb}/_{TPbProd}$ (EST,MAX CONC)	$1.1x10^{-1}{}^{lb}/_{TPbProd}$ (EST, AVE CONC)	2,7,8,10,11
Blast Furnace w/Baghouse			$5.25x10^{-3}{}^{lb}/_{TPb}$(STK,ES)	14
COPPER				
Uncontrolled Smelter	$7x10^{-2}{}^{lb}/_{TCu}$ (EST,MB)	$2.9x10^{-1}{}^{lb}/_{TCu}$ (EST,MB)	$1.5x10^{-1}{}^{lb}/_{TCu}$	2,7,8,10
Smelter w/Baghouse (~95%)			$7x10^{-3}{}^{lb}/_{TCu}$ (EST)	8
CADMIUM	$25^{lb}/_{TCdProd}$ (EST,SURV,MB)	$30.5^{lb}/_{TCdProd}$ (EST,MB)	$28^{lb}/_{TCd}$	7,8,10
SECONDARY METALS PROCESSING				
IRON & STEEL				
Sinter Windbox-Uncontrolled	$1.35x10^{-3}{}^{lb}/_{TFeed}$ (STK,ES)	$2.63x10^{-3}{}^{lb}/_{TFeed}$ (STK,ES)	$2x10^{-3}{}^{lb}/_{TFeed}$	14
Sinter Windbox w/Rotoclone & ESP	$9.32x10^{-4}{}^{lb}/_{TFeed}$ (STK,ES)	$9.76x10^{-4}{}^{lb}/_{TFeed}$ (STK,ES)	$9.5x10^{-4}{}^{lb}/_{TFeed}$	14
Blast Furnace-Controlled			- 0 (EST)	51
Open Hearth-Uncontrolled	$4.08x10^{-3}{}^{lb}/_{TSteel}$ (STK,AA)	$6.48x10^{-3}{}^{lb}/_{TSteel}$ (STK,AA)	$5.78x10^{-3}{}^{lb}/_{TSteel}$ (STK,AA)	5
Open Hearth w/ESP	$2.08x10^{-5}{}^{lb}/_{TSteel}$ (EST,CONC)	$1.34x10^{-4}{}^{lb}/_{TSteel}$ (STK,AA)	$1.1x10^{-4}{}^{lb}/_{TSteel}$ (STK,AA)	5,11,12,15,17
Basic Oxygen Furnace				
Uncontrolled			$4.1x10^{-5}{}^{lb}/_{TSteel}$ (CONC)	15
w/Venturi or ESP	$3.45x10^{-6}{}^{lb}/_{TSteel}$ (STK,ES)	$2.79x10^{-5}{}^{lb}/_{TSteel}$ (STK,ES)	$1.2x10^{-5}{}^{lb}/_{TSteel}$	14
Electric Arc Furnace	$2.7x10^{-3}{}^{lb}/_{TSteel}$ (EST,CONC)	$5x10^{-3}{}^{lb}/_{TSteel}$ (EST,STK,CONC)	$3.4x10^{-3}{}^{lb}/_{TSteel}$ (EST,STK, CONC)	14,15
SECONDARY ZINC-UNCONTROLLED	$8x10^{-3}{}^{lb}/_{TZn}$ (SURV,MB)	$1.4x10^{-2}{}^{lb}/_{TZn\ Prod}$ (MB)	$1x10^{-2}{}^{lb}/_{TZn\ Prod}$	2,7,8,18,21
SECONDARY LEAD				7,10,18
Blast Furnace w/3 Cyclones & Baghouse	$5.9x10^{-7}{}^{lb}/_{TPb}$ (STK,ES)	$3.5x10^{-5}{}^{lb}/_{TPb}$ (STK,ES)	$2x10^{-6}{}^{lb}/_{TPb}$	14
Reverberatory Furnace w/ Cyclone & Baghouse	$5.9x10^{-7}{}^{lb}/_{TPb}$ (STK,ES)	$4x10^{-4}{}^{lb}/_{TPb}$ (STK,ES)	$1.6x10^{-6}{}^{lb}/_{TPb}$	7,14
Reverberatory Furnace w/ 3 Cyclones & Baghouse	$6.5x10^{-9}{}^{lb}/_{TPb}$ (STK,ES)	$2x10^{-4}{}^{lb}/_{TPb}$ (STK,ES)	$5x10^{-7}{}^{lb}/_{TPb}$	7,14
SECONDARY COPPER-UNCONTROLLED	$2.6^{lb}/_{TCu\ Scrap}$ (EST,MB)	$4^{lb}/_{TCu\ Scrap}$ (EST,MB)	$3^{lb}/_{TCu\ Scrap}$	7,8
MINING OF CADMIUM-BEARING ORES			$2x10^{-1}{}^{lb}/_{TCd\ in\ Ore}$ (EST,MB)	5,2,7,21
Zinc Ore			$1x10^{-3}{}^{lb}/_{TZn\ in\ Ore}$ (EST,MB)	2,3
Lead Ore			$1x10^{-4}{}^{lb}/_{TPb\ in\ Ore}$ (EST,MB)	2,3
Copper Ore			$3.2x10^{-5}{}^{lb}/_{TCu\ in\ Ore}$ (EST,MB)	2,3
MANUFACTURING				
Alloys & Solders-Controlled			$10^{lb}/_{TCd\ Charged}$ (SURV)	2,7
Pigments w/Baghouse			$15^{lb}/_{TCd\ Charged}$ (EST,MB)	2,7
Stabilizers (for Plastics) w/Baghouse			$6^{lb}/_{TCd\ Charged}$ (EST,SITE)	2,7
Batteries (Ni-Cd)			$2^{lb}/_{TCd\ Charged}$ (SURV)	2,7
Miscellaneous (X-Ray Screens, Cathode Ray Tubes, Nuclear Reactor Components,etc.)			$2^{lb}/_{TCd\ Charged}$ (EST)	2,7

TABLE E-2 (continued)

CADMIUM EMISSION FACTORS

SOURCE	MINIMUM	MAXIMUM	BEST JUDGEMENT	REFERENCES
FOSSIL FUEL COMBUSTION				
Coal-Fired Power Plants				
Uncontrolled	$1x10^{-4}$ lb/TCoal (STK,AA)	$1x10^{-1}$ lb/TCoal (STK,ES)	$1x10^{-3}$ lb/TCoal	14,22,23
Controlled (ESP)	$1x10^{-6}$ lb/TCoal (STK,AA)	$7x10^{-4}$ lb/TCoal (STK,AA)	$6x10^{-5}$ lb/TCoal	7,8,10,15,21,31
Oil-Fired Power Plants				
Controlled (~ ESP)	$7.1x10^{-7}$ lb/gal (STK,ES)	$4.4x10^{-6}$ lb/gal (STK,CONC,ES)	$9x10^{-7}$ lb/gal (STK,ES)	14
Heating Oil (Residual; #6 Fuel Oil)	$1.5x10^{-6}$ lb/gal (EST,CONC)	$4x10^{-5}$ lb/gal (EST,CONC,NA)	$3x10^{-6}$ lb/gal	2,7,10,21,18,26,33
Diesel Oil	$6x10^{-7}$ lb/gal (EST,CONC,ES)	$2x10^{-6}$ lb/gal (EST)	$7x10^{-7}$ lb/gal (EST,CONC,ES)	7,10,21,18
Gasoline (for 15 mpg, all Cd Emitted)	$6.3x10^{-11}$ lb/veh-mi (EST, CONC)	$4.5x10^{-8}$ lb/veh-mi (EST,CONC)	$2x10^{-8}$ lb/veh-mi	25,26,27,28,29
SEWAGE SLUDGE INCINERATORS				
Multiple Hearth w/Scrubber	$1x10^{-6}$ lb/TSludge (DRY)(STK, ES)	$2x10^{-5}$ lb/TSludge (DRY) (STK,ES)	$7x10^{-6}$ lb/TSludge (DRY) (STK, ES)	7
Fluidized Bed w/Scrubber	$4x10^{-7}$ lb/TSludge (DRY) (STK,ES)	$3x10^{-6}$ lb/TSludge (DRY)(STK,ES)	$1.3x10^{-6}$ lb/TSludge (DRY)(STK, ES)	7,14
MUNICIPAL INCINERATORS				
Uncontrolled	$3x10^{-3}$ lb/TRefuse (EST)	$1.8x10^{-2}$ lb/TRefuse (STK,ES)	$6x10^{-3}$ lb/TRefuse (STK,ES)	7,10,14
Controlled (Scrubbers or ESP)	$6x10^{-4}$ lb/TRefuse (FLAA)	$1.0x10^{-1}$ lb/TRefuse (EST,MB)	$1.3x10^{-2}$ lb/TRefuse (STK,AA)	5,7,8,10,14,33
LUBRICATING OIL INCINERATORS				
Uncontrolled			$2x10^{-6}$ lb/gal (UNK)	7
MISCELLANEOUS				
Motor Oil Consumption (Vehicles)	$1x10^{-10}$ lb/veh-mi (EST,CONC)	$5x10^{-8}$ lb/veh-mi (EST,CONC)	$2x10^{-9}$ lb/veh-mi (UNK)	7,8
Rubber Tire Wear	$4.8x10^{-6}$ lb/gal (EST,MB)	$5x10^{-5}$ lb/gal (EST)	$8x10^{-9}$ lb/veh-mi	2,6,7,10
Fungicides Application	$1.7x10^{-4}$ lb/T (EST,MB)	$5x10^{-2}$ lb/T (EST,MB)	$1x10^{-5}$ lb/gal	7,8
Fertilizers Application			$6x10^{-3}$ lb/T	6,7,8,17,21,31
Superphosphate Fertilizers Application			$2x10^{-4}$ lb/T	6,7,31
CEMENT PLANTS				
DRY PROCESS				
Kiln w/Baghouse or ESP				
Raw Mill Feed w/Baghouse	$3x10^{-7}$ lb/TFeed (STK,ES)	$4.1x10^{-7}$ lb/TFeed (STK,ES)	$3x10^{-4}$ lb/TFeed (STK,ES)	7
Raw Mill w/Baghouse	$1x10^{-7}$ lb/TFeed (STK,ES)	$4.3x10^{-7}$ lb/TFeed (STK,ES)	$3.6x10^{-7}$ lb/TFeed	7,14
Raw Mill Air Separator w/ Baghouse	$7.6x10^{-7}$ lb/TFeed (STK,ES)	$9x10^{-7}$ lb/TFeed (STK,ES)	$2.7x10^{-7}$ lb/TFeed	7,14
Finish Mill Feed w/ Baghouse	$5x10^{-7}$ lb/TFeed (STK,ES)	$1.6x10^{-6}$ lb/TFeed (STK,ES)	$8.5x10^{-7}$ lb/TFeed	7,14
Finish Mill w/Baghouse		$1.3x10^{-7}$ lb/TFeed (STK,ES)	$1x10^{-6}$ lb/TFeed	7,14
Finish Mill Air Separator w/Baghouse			$1x10^{-7}$ lb/TFeed	14
WET PROCESS				
Kiln w/ESP	$7.4x10^{-6}$ lb/TFeed (STK,ES)	$2x10^{-4}$ lb/TFeed (STK,ES)	$2.6x10^{-6}$ lb/TFeed (STK,ES)	14
Raw Mill w/Baghouse			$2x10^{-5}$ lb/TFeed	7,14
Clinker Cooler w/ESP or Baghouse	$1.7x10^{-6}$ lb/TFeed (STK,ES)	$1x10^{-4}$ lb/TFeed (STK,ES)	$2x10^{-5}$ lb/TFeed	14
LIME KILN (PULVERIZED COAL)			$1x10^{-5}$ lb/TFeed	7,14
Kiln w/Spray, Settle & Baghouse	$4.6x10^{-5}$ lb/TFeed (STK,ES)	$6.9x10^{-5}$ lb/TFeed (STK,ES)	$5.7x10^{-5}$ lb/TFeed	14

a/ EST = Estimate; MB = Mass Balance; SITE = Site Visits; SURV = Survey of Companies; UNK = Unknown (in literature); STK = Stack Sampling Results; CONC = Concentration of Cd in feed, fuel, or emissions (w/STK); ES = Emission Spectroscopy; AA = Atomic Absorption (FL-Flame); NA = Neutron Activation Neutron Activation.

accomplished by modeling a very large plant in each category under restrictive assumptions of stack height, flow rate, temperature and meteorology. The evaluation procedure was not designed to determine what expected levels of cadmium might be, but to determine if any possibility existed that the source could cause a measurable level. A more detailed modeling effort was undertaken during the cadmium exposure analysis.

Table E-3 lists the source categories which were determined to be potentially able to cause a measurable level of cadmium. These sources were further evaluated in the second phase of this study to determine the population potentially exposed.

TABLE E-3

SOURCE CATEGORIES POTENTIALLY ABLE TO
CAUSE A MEASURABLE LEVEL OF CADMIUM

Primary Zinc Smelters
Primary Copper Smelters
Primary Lead Smelters
Primary Cadmium Smelters
Secondary Zinc Smelters
Secondary Copper Smelters
Municipal Incinerators
Iron and Steel Mills

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a/ Assumed to be 0.1 ng/m^3 on an annual average.

1. INTRODUCTION

This report is one in a series of reports which will be used to help EPA respond to the Congressional mandate under Section 122 of the Clean Air Act Amendments of 1977. Under this section, EPA is required to review the health and welfare effects of cadmium (as well as other substances) and determine "whether or not emissions of...cadmium...into the ambient air will cause, or contribute to, air pollution which may reasonably be anticipated to endanger public health."

This report focuses on three of the areas of information required to make this determination--identification of the uses and sources of cadmium, development of emission factors for cadmium from industrial sources, and the screening of cadmium sources to determine which ones are potentially "significant" sources of ambient cadmium. In this report, a "significant" source is defined as one which, by itself, can cause a measurable ambient level of cadmium.

A companion study[1/] uses the results from this study to provide an estimate of the population exposed to measurable levels of cadmium. Neither this report, nor the companion report on population exposure, draws any conclusions as to the health consequences of ambient cadimum levels. Rather, the purpose of the two reports is to provide a relative ranking of sources, both by the magnitude of emissions and the population exposed, and to provide information in such a way as to allow EPA to make reasonable estimates of any health implications of the reported emissions and exposures.

The report is organized into five substantive sections summarized below:

- Section II provides an overview of the physical and chemical properties of cadmium, as well as the routes through which cadmium exposure can occur.

- Section III provides an overview of the metholodogy used in preparing this report.

- Section IV discusses the current and expected uses of cadmium.

- Section V discusses the potential emission sources of cadmium. For each source, a brief description of the process, cadmium emission points, and the emission factors are described. Total current and expected cadmium emissions and available control technology are also discussed.

- Section VI discusses the screening of the various cadmium sources which was used to determine which sources can cause a measurable level of cadmium (0.1 ng/m^3 on an annual average).

REFERENCES

1. Cadmium: Population Exposure Analysis, Energy and Environmental Analysis, Final Report, Contract No. 68-02-2836, Task 14, March 2, 1979.

2. CADMIUM IN THE ENVIRONMENT

2.1 INTRODUCTION

This section discusses the physical and chemical properties of cadmium and the multimedia nature of cadmium exposures. Although this report focuses only on atmospheric emissions of cadmium, it is important to keep in mind that there are many other types of human exposure to cadmium.

2.2 PHYSICAL AND CHEMICAL CHARACTERISTICS OF CADMIUM

Cadmium is a relatively rare element in the earth's crust. It occurs at concentrations of 0.1 to 0.5 ppm, ranking in abundance between mercury and silver, and thus, not in sufficient quantities to be mined as an ore.[1/] Table 2-1 shows the physical properties of cadmium. Cadmium is always associated with zinc and is usually present as a sulfide.[2/]

The most important characteristic of cadmium, from an air pollution viewpoint, is its high volatility. This is evidenced by its low melting (321^{o}C) and boiling (767^{o}C) points. Because of this, high temperature processes, such as metallurgical processes (steelmaking, sintering) or incineration, are likely to release whatever cadmium is present in their feeds. Vaporized cadmium metal reacts very quickly to form an oxide, sulfate, or other compound of relatively high stability. Cadmium metal is also ductile, easily soldered, and can be readily electroplated to maintain a lustrous finish in air.[3/] These properties lead to the use of cadmium as a protective coating on iron and steel products.

2.3 MULTI-MEDIA NATURE OF CADMIUM EXPOSURES

While this report focuses on the atmospheric emissions of cadmium, it is important to recognize the overall cycle of cadmium in the environment.

Measurable levels of cadmium occur in all phases of environmental concern (air, water, food, solid waste), and in almost all areas. One author[1/] refers to cadmium as the "dissipated element." EPA in 1975[5/] estimated that about 1,800 Mg/year of cadmium were lost to the environment. Of this, about 18 percent was in atmospheric emissions, 75 percent in solid waste, and the remainder in water-borne emissions.

Measurable cadmium levels have been found in air, water, soil and food. Atmospheric concentrations generally have been measured in the center of urban areas and usually range from 100 ng/m^3 down to below the detectable limit. Typical urban concentrations would be approximately 3 ng/m^3; some measured values appear in Table 2-2. Levels of cadmium in water supplies are generally low. Main sources of cadmium are discharges from mining operations, leaching from soil disposal of wastes, and rain-out from atmospheric emissions.

Cadmium in food results from a wide variety of sources. Listed in order of importance from a recent Battelle Report,[4/] they are:

- Direct contact by plants or uptake from soils by plant roots. Cadmium may occur in soil:
  - Naturally as a normal constituent of all soils, but particularly those of marine origin.
  - As an impurity (cadmium oxide) in phosphate-treated soils, especially in those treated with "superphosphate."
  - By fertilization with sludge containing cadmium.
  - By deposition of cadmium-containing pesticides or a contaminant of zinc-containing pesticides.
  - From run-off of mine tailings or from electroplating washing process.

- Accumulation in animal tissues due to:
  - Feeding on crops which have absorbed cadmium. (The organs of such animals may have very high cadmium concentrations.)
  - Treatment with cadmium-containing helminth killers, used especially in swine.
  - Concentrations of cadmium by mollusks and crustaceans and most other aquatic organisms from ambient waters.
- Use of zinc-galvanized containers, cans, cooking implements or vessels; or utensils used in food preparation, particularly grinders, pressing machines, or galvanized netting used to dry fish and gelatin.
- Absorption of cadmium contained in wrapping and packaging materials such as paper, plastic bags, and tin cans. (Cadmium is now prohibited in such food wrappings.)
- Use of cadmium-contained water in cooking or processing operations.

Table 2-3 lists the average cadmium concentration of selected adult foods.

Cigarette smoking also provides a large contribution to total cadmium exposure. The estimated intake from two packs per day ranges from four to six micrograms which amounts to about 20 times the exposure due to atmospheric levels in large urban areas.

Even for smokers, food provides the greatest overall exposure to cadmium, and based on a 6.4 percent retention rate, the greatest daily input (except for three packs-per-day-smokers). Table 2-4 summarizes the sources of cadmium exposure.

TABLE 2-1

PHYSICAL PROPERTIES OF CADMIUM[a,b/]

Atomic Number	48
Atomic Weight	112.41
Color	silver-white
Crystal Structure	hexagonal pyramids
Hardness	2.0 Mohs
Ductility	Considerable
Density	
20°C (68°F) (solid)	8.5 g/cc
330°C (626°F) (liquid)	8.01 g/cc
Melting point	321°C (609.8°F)
Boiling point	767°C (1412.6°F)
Specific heat	
25°C (77°F) (solid)	0.055 g-cal/g
Electrochemical equivalent	
Cd^{++} ion	0.582 mg/coulomb
Electrode potential	
Cd^{++} ion	0.40 volt[a/]

a/ From Reference 1.

b/ National Bureau of Standards nomenclature, H_2.

TABLE 2-2

SOME ATMOSPHERIC CADMIUM DATA[a/]

SITE	CONCENTRATION (ng/m^3)
URBAN:	
Liege, Belgium	118
Paris, France	20
Sevastopol, USSR	2.3
Petropavlovsk, USSR	0.6
Magadan, USSR	4.2
Salehard, USSR	5.3
Dourbes, Belgium	1.3
Heidelberg	27
Rotterdam	7.7
Sutton, England	0.4
San Francisco	20
Cincinnati	2.0
Denver	1.0
St. Louis	5.0
Washington, D.C.	0.3
Chicago	3.0
Philadelphia	1.0
Tucson	3.4
Oak Ridge, TN	4.1
New York City	5.7
New York Bight	1.0
U.S. urban average (1966)	2.0
REMOTE:	
Northern Norway	0.5 (lowest 0.006)
Jungfraujoch, Switzerland	0.4
Novaya Zemlya	0.3
Dickson Island, USSR	0.4
Indian Ocean, North	2.0
Indian Ocean, South	0.14
Bermuda	0.4
North Atlantic	4.2
Windward Hawaii	0.02
South Pole	<0.02
Spitsbergen	0.1
Barrow, Alaska	0.04

a/ Source: Reference 4

TABLE 2-3

CADMIUM CONTENT OF SELECTED ADULT FOODS[a/]

Commodity	No. of Samples	Average ppm	Standard Deviation, ppm
Carrots, roots fresh	69	0.051	0.077
Lettuce, raw crisp head	69	0.062	0.124
Potatoes, raw white	71	0.057	0.139
Butter	71	0.032	0.071
Margarine	71	0.027	0.048
Eggs, whole fresh	71	0.067	0.072
Chicken fryer, raw whole or whole cut up	71	0.039	0.088
Bacon, cured raw, sliced	71	0.040	0.160
Frankfurters	69	0.042	0.111
Liver, raw beef	71	0.183	0.228
Hamburger, raw ground beef	71	0.075	0.122
Roast, chuck beef	71	0.035	0.034
Wheat flour, white	71	0.064	0.150
Sugar refined, beet or cane	71	0.100	0.709
Bread, white	70	0.036	0.063
Orange juice, canned frozen concentrate	71	0.029	0.095
Green beans, canned	71	0.018	0.072
Beans, canned with pork and tomato sauce	71	0.009	0.000
Peas, canned	71	0.042	0.113
Tomatoes, canned	71	0.042	0.113
Diluted fruit drinks, canned	71	0.017	0.052
Peaches, canned	71	0.036	0.061
Pineapple, canned	71	0.059	0.153
Applesauce, canned	71	0.020	0.027

a/ Source: Reference 4

TABLE 2-4

MEDIA CONTRIBUTIONS TO NORMAL RETENTION OF CADMIUM[a/]

Medium	Exposure Level	Daily Retention (µg)
Ambient air	0.03 µg/m^3	0.15
Water	1 ppb	0.09
Cigarettes:		
Packs/Day	µg/day[b/]	
1/2	1.1	0.70[c/]
1	2.2	1.41[c/]
2	4.4	2.82[c/]
3	6.6	4.22[c/]
Food	50 µg/day	3.0

a/ Source: Reference 4.

b/ Based on 0.11 µg per cigarette.

c/ Assumes a 6.4 percent retention rate.

REFERENCES

1. Fulkerson, W., and Goeller, H.D., Eds., Cadmium, The Dissipated Element, ORNL National Science Foundation, ED-21, January 1973.

2. Deane, G. L., Lynn, D.A., and Surprenant, N.F., Cadmium: Control Strategy Analysis, GCA-TR-75-36-G, Final Report for Environmental Protection Agency, Contract No. 68-02-1337, Task No. 2, April 1976.

3. Sargent, D.J. and Metz, R.J., Technical and Microeconomic Analysis of Cadmium and Its Compounds, Environmental Protection Agency, 560/3-75-005, June 1975.

4. Multimedia Levels Cadmium, Environmental Protection Agency 560/6-77-032, September 1977.

5. Scientific and Technical Assessment Report on Cadmium, Environmental Protection Agency 600/6-75-003, March 1975.

3. METHODOLOGY

3.1 INTRODUCTION

This section describes the general methodology used in evaluating sources of cadmium emissions and in determining their magnitude and significance. In simplest terms, the methodology can be viewed as having five components:

- Determination of potential cadmium emission sources;
- Determination of emission factors for these sources;
- Estimation of current and future emissions of cadmium;
- Evaluation of control technology for reducing cadmium emissions from these sources; and
- Screening of all potential cadmium sources to identify the sources most likely to cause measurable ambient levels.

3.2 DETERMINATION OF POTENTIAL CADMIUM EMISSION SOURCES

A literature search and a review of previous EPA studies were carried out to determine the sources most likely to emit cadmium. The basic procedure followed in this study, as well as in previous studies, was to concentrate on the production and uses of cadmium, and then to follow cadmium through to its ultimate disposal.

Once the potential sources were identified, trade literature and other references were used to develop process descriptions, identify potential emission sources, and estimate total current and projected production. Special emphasis was placed on determining changes in production patterns which could lead to changes in emission characteristics. The subsections of Section V, which discuss each industry, identify the data used to develop the above information.

3.3 EMISSION FACTOR DETERMINATION

For each potential cadmium source identified, the literature was surveyed to determine the amount of cadmium emitted per product unit produced. For most sources, several types of data were available and a ranking system was established to determine the final emission factor. The data were ranked in the following order:

- Actual Stack Tests--Stack tests conducted on several sources, or even one source, and analyzed by a quantitative analytic technique such as atomic absorption (AA). Stack tests conducted using a semi-quantitative technique such as emission spectroscopy (ES) were given a somewhat lower ranking. The primary source of stack tests using ES was EPA tests in support of particulate new source performance standards.

- Concentration of Cadmium in Feed--For fuel burning sources, data on incoming cadmium levels can be used to determine cadmium emissions relatively accurately if 100 percent loss of cadmium is assumed. This assumption is reasonable because of the high volatility of cadmium.

- Mass Balances--For several sources, the only data available came from an estimate of the losses of cadmium during processing. Data comes from site visits carried out by EPA during earlier emission factor development and engineering judgement on process operations.

For each source type, several emission factors were developed:

- Minimum Emission--Lowest emission factor reported by any study.

- Maximum Emission--The highest emission factor reported by any study.

- Best Judgement--The best estimate of emissions when the quality of all the data is considered and the ranking system described above is used. Often, a mean was used for a series of stack tests of equal quality. Where emission factor estimates range from mass balances to tests using atomic absorption, the best judgement was weighted subjectively toward the more accurate AA estimates.

As with any substance, cadmium emissions can vary greatly from source to source, and the accuracy of any specific emission factor for a specific plant is questionable.

The emission factors developed here are probably sufficiently accurate for the purposes intended, (relative evaluation among source categories), but care should be taken in applying the factors to any specific plant.

3.4 COMPUTATION OF EMISSION LEVELS

The production levels for each source category and the emission factors previously developed were combined to provide an estimate of total current cadmium emissions. The emission factors were modified (where necessary) to reflect the application of typical control technology. For purposes of comparison, where EEA's control technology assumptions differed from those in previous estimates, an additional estimate for cadmium emissions was made using comparable control technology assumptions.

3.5 SOURCE SCREENING

To determine which source types are capable of causing a measurable level of cadmium, (assumed to be an annual average of 0.1 ng/m^3) a screening procedure was developed. While the detailed procedure for screening varied from source type to source type, (each is discussed in Section VI) the general procedure is as follows:

- For each source type, an expected largest or very large source was determined from the literature.
- A very conservative combination of stack conditions was then determined. These conditions (stack height, temperature, flow, etc.) were based on engineering judgement, coupled with limited data available in the literature. Every assumption was made such that ground level concentrations would be maximized.
- Emissions were based on maximum emission factors and plants were assumed to produce their rated capacity in only eight hours of operation.

- Ambient concentrations (for point sources) were determined using the EPA "PTMAX" model. If these concentrations exceeded the detectable limit, (0.1 ng/m^3) further analysis was required. This criterion is extremely conservative because the PTMAX estimates one-hour concentrations, which are typically at least ten times higher than annual averages.

4. USES OF CADMIUM

4.1 INTRODUCTION

Consumption of cadmium in the United States has averaged approximately 5,000 metric tons a year over the past several years. In 1975, almost 40 percent of the cadmium used in the U.S. was imported.

There are four major uses of cadmium, all of which are dissipative (Figure 4-1). In 1974, approximately 55 percent (2,700 metric tons) of the cadmium consumed in the U.S. was used by the electroplating industry. Paint pigment manufacturing required close to 1,000 metric tons of cadmium in 1974, and 900 metric tons were used to produce plastic stabilizers.[1/] The fourth major use of cadmium in 1974 was the nickel-cadmium battery, for which 550 metric tons of the metal were used.[1/] Cadmium is also used in nuclear reactor controls, fluorescent phosphors, and in alloys.[1/]

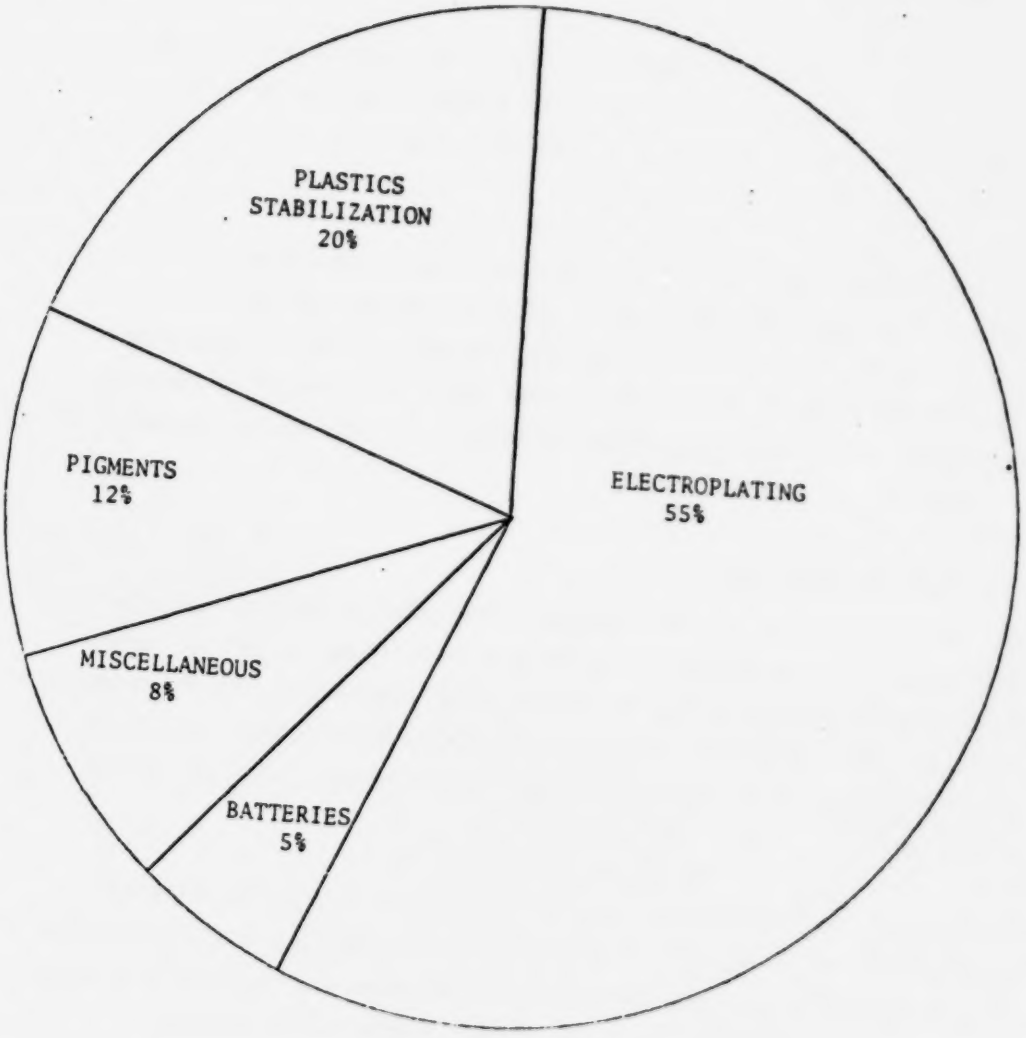
4.2 ELECTROPLATING

Electroplating a metal with cadmium inhibits corrosion and enhances solderability. Products made of iron and steel are most frequently coated with cadmium, including motor vehicle parts, industrial machinery parts, aircraft parts, marine equipment, and hardware.

There are several reasons why cadmium is preferred as a coating material. Only a thin coating is necessary to provide adequate protection from corrosive elements, especially salt water and alkalies. It is possible to obtain a uniform deposition on objects of intricate design, and luster is maintained for a long period of time. Although several substitutes exist, cadmium is believed to be superior.

FIGURE 4-1

1975 CADMIUM CONSUMPTION IN THE UNITED STATES(1)



4.3 PAINT PIGMENTS

Paint pigment production accounted for approximately 12 percent of the 1975 U.S. consumption of cadmium. The cadmium-sulfide compounds are used to obtain colors ranging from yellow to orange, while the cadmium-sulfoselenide compounds produce colors ranging from orange to light red and deep maroon.

It has been estimated that approximately 75 percent of the pigments are used to color plastic. Other uses for cadmium pigments include water-based paints, rubber, artists' colors, printing inks, glass, textiles, enamels, and ceramic glazes.

Cadmium pigments have certain properties which render them difficult to replace. Because they are totally non-bleeding and alkali-resistant, they are particularly suitable for plastic automobile interior parts. The pigments provide very bright colors and a high degree of opacity. Their high temperature properties contribute to the unique character of the pigment.

4.4 PLASTIC STABILIZERS

The third major consumer of cadmium is the plastic stabilizer industry. Heat stabilizers containing cadmium have been found to halt or slow discoloration caused by the breakdown of polyvinyl chloride resin during molding. The stabilizers are found in almost every plastic material with the exception of food packaging, where use is prohibited by FDA regulations.[1/]

Substitutes for the cadmium plastic stabilizers may be forthcoming in light of FDA regulations. Stabilizers of calcium-zinc composition have been found to be competitive in both performance and cost and are expected to replace the cadmium stabilizer in some items in the future.

4.5 NICKEL-CADMIUM BATTERIES

The nickel-cadmium battery is the fourth major product composed of cadmium. Demand for cadmium in this segment of the industry tripled between 1968 and 1973. Batteries range in size from small button cells (614 mm in diameter) to large rectangular cells (113 mm high by 91 mm long by 38 mm wide).

The nickel-cadmium battery is used in a variety of systems and products including alarm systems, pacemakers, and portable appliances and tools. Calculators presently are the largest market for the battery. The nickel-cadmium battery is preferable to others if long life is important.

4.6 MISCELLANEOUS

Cadmium is also used to produce alloys, (primarily low temperature solders), silver bronzes, and a copper alloy used in automobile radiators. Nuclear reactor rods are often made of silver-cadmium. Cadmium phosphates are used for television and fluorescent tubes; silver-cadmium oxide is used in motor starting switches, relays, and circuit breakers.

REFERENCES

1. Determination and Evaluation of Environmental Levels of Cadmium, EPA 68-01-1983, Battelle-Columbus Laboratories, Columbus, Ohio, 1977.

2. Sargent, D.J. and Metz, J.R., Technical and Microeconomic Analysis of Cadmium and Its Compounds, Environmental Protection Agency, 560/3-75-005, June 1975.

5. SOURCES OF ATMOSPHERIC CADMIUM EMISSIONS

5.1 INTRODUCTION

Cadmium, a relatively rare element in the earth's crust, does not occur alone naturally. It is a metal found only in conjunction with other metallic ores, principally zinc, lead, and copper. When released into the environment, cadmium can be absorbed, ingested or inhaled by biological systems, causing subsequent damage to these systems. This study focuses upon one form of environmental release--emission to the atmosphere.

Airborne cadmium emissions result from the production of cadmium, its use (primarily dissipative), and the use of other substances which are contaminated with cadmium. Cadmium is produced commercially as a by-product of the primary production of zinc and is found in the ores of lead and copper also. As a result, the mining and primary smelting of these three metal ores produce approximately 63 percent of the cadmium emitted to the air. Cadmium is a major constituent in the production of paint pigments, metal alloys, plastic stabilizers, and nickel-cadmium batteries. Metals are often electroplated with cadmium. Substances which contain cadmium as a contaminant include phosphatic fertilizers, sewage sludge, fossil fuels, cement, and fungicides. All of these materials contribute to the atmospheric emission of cadmium.

Each process which contributes to the amount of cadmium in the air is described in the following sections, together with control devices used and national production trends for the near future.

5.2 MINING

The mining of zinc, lead, and copper is a source of airborne cadmium emissions, though the quantities emitted are small-less than one ton a year.

5.2.1 Process

The process of preparing each metal ore for shipment to a primary smelter involves two steps, mining and beneficiation. First, the large chunks of ore are removed from the ground, crushed, and ground to fine, sand-sized particles. The concentration process which follows is most often done using a combination of gravity and flotation mechanisms, or by flotation alone; however, some plants use only gravity settling. At this point, any cadmium in the ore is present in the zinc concentrate. Ore beneficiation is usually conducted in close proximity to the mine, particularly in the Western States.

5.2.2 Emissions Source and Control

The major emissions from this phase of the metal production are a result of the dust which escapes during mining and crushing. Because beneficiation is a wet process, air emissions from this phase are minimal. Control methods are rarely needed or used during the ore-crushing procedures due to the effective design of the equipment; however, in any raw material handling, a hood and a cyclone, baghouse, or the electrostatic precipitator (ESP) is used.[1/] Although no information is available as to the extent of the problem, airborne particulates from mine tailing piles may be a possible source of cadmium emissions.

5.2.3 Emission Estimate

Emission factors used in this estimate were 1×10^{-3} pounds/ton of zinc in the ore,[2,3/] 1×10^{-4} pounds/ton of lead in the ore,[2,3/] and 3.2×10^{-5} pounds/ton[2,3/] of copper in the ore. Production of ore at various

mines in 1974 equaled 478,850 tons of zinc ore,[12/] 603,024 tons of lead ore,[12/] and 1,414,246.8 tons of copper ore.[12/] From these emission factors and production figures, the emissions estimate of less than one ton of cadmium per year was developed. Estimates from other organizations are in agreement with EEA's, as similar emission factors were used (GCA--1 ton[2/]; Mitre--1 ton[11/]; Davis--1 ton[7/]; EPA--1 ton[6/]).

5.2.4 Future Trends

It is believed that the mining of the various metal ores will increase significantly, to the 1985 levels shown in Table 5-1. Even with this increase, cadmium emissions from mining and ore beneficiation are predicted to remain below one ton/year.

5.3 PRIMARY METAL PRODUCTION

Primary metal production involves conversion of an ore concentrate to a relatively pure metal. Three primary metal production processes--zinc, lead, and copper--are responsible for over 60 percent of all airborne cadmium emissions.

5.3.1 Primary Zinc

5.3.1.2 Process

The primary smelting of zinc produces both zinc and cadmium metal and thus produces airborne cadmium emissions. There are two basic methods used to obtain the desired output--pyrometallurgical and electrolytic extraction. The first step in each process is the roasting of the zinc concentrate, during which zinc sulfide is converted to zinc oxide. The sulfur which escapes from this process is often converted to sulfuric acid in a contact process acid plant.

In the pyrolytic reduction of the ore, the next step is sintering, which renders the material easier to handle and use as feed. Smelting of the

zinc oxide follows the sintering. Smelting is conducted in batches in horizontal retorts or continuously in vertical retorts, electrothermic furnaces, or blast furnaces. Addition of carbon to the zinc oxide at this point indirectly aids reduction of the oxide to the zinc metal, as it reacts more readily with oxygen than does the zinc. The metal is then vaporized, transferred from smelter to condensers, converted to molten zinc, and cast into slab zinc. Slab zinc is frequently purified further by redistillation.

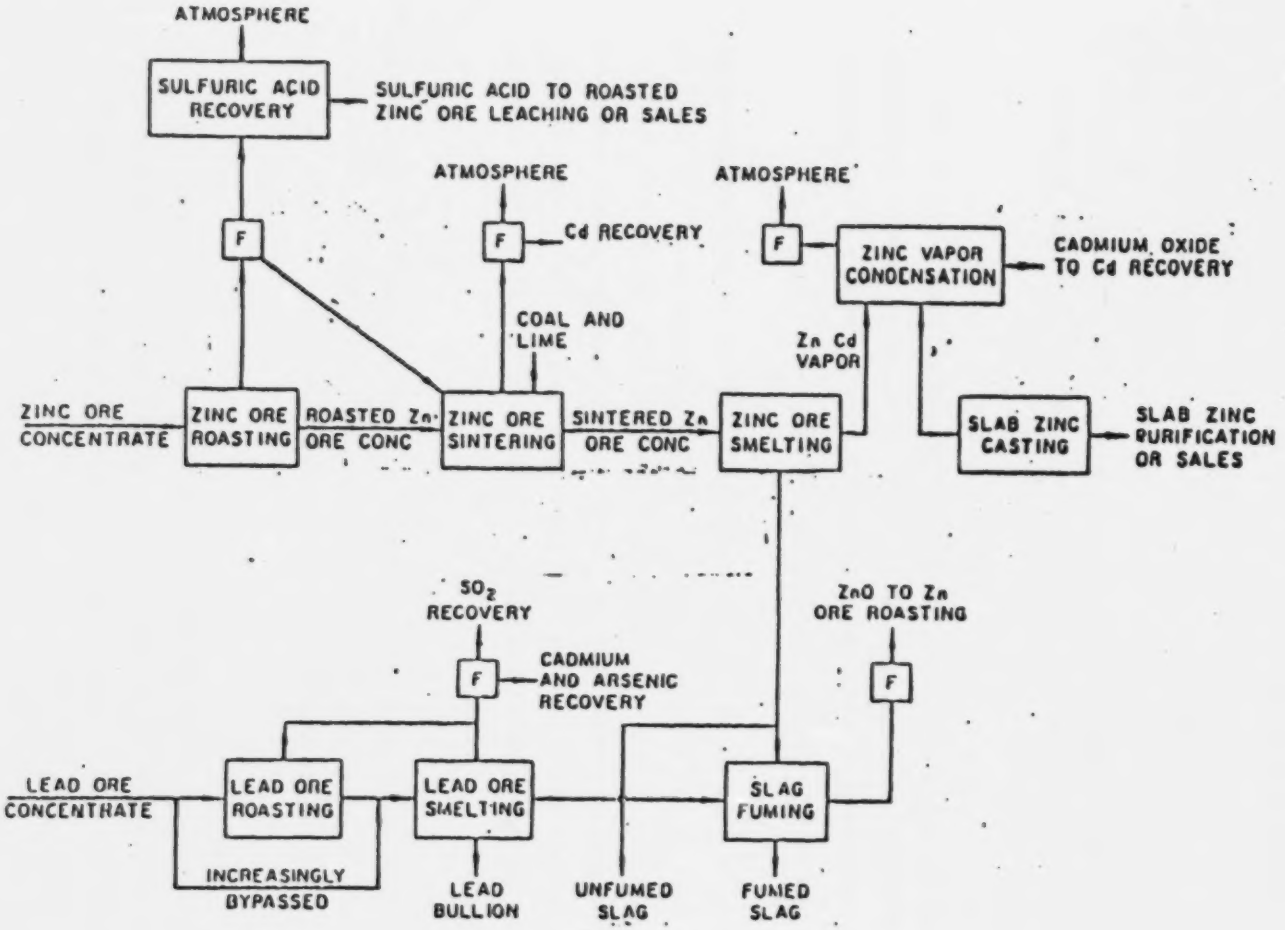
Electrolytic zinc recovery was developed chiefly for the processing of low-grade or mixed ore concentrates. As high grade zinc deposits are depleted, this process will assume an increasingly important role in the processing of zinc (and other metals).

Beyond the step of roasting, there is no similarity between the electrolytic and pyrometallurgical processes. In electrolytic recovery, the roasted zinc ore is leached with sulfuric acid to produce soluble zinc sulfates. Filtration to remove insoluble impurities (including cadmium) is followed by treatment of the solution with zinc dust. This treatment is done twice--first to remove copper impurities, and then to produce a zinc-cadmium residue. It is possible to continue further processing of these residues to recover the copper and cadmium contained in them.

In the next step, zinc metal is produced by processing of the zinc sulfate solution in electrolytic cells. The zinc is then electrodeposited onto aluminum cathodes. At regular intervals, the cathodes are removed from the electrolytic cells, the zinc is stripped from the aluminum, and then melted to produce slab zinc. Slab zinc produced in this manner does not usually require any additional refining, as it is of very high purity. It is not possible to process scrap in this manner because it contains too many impurities. (Figure 5-1 illustrates the primary zinc smelting process.)

FIGURE 5-1

PRIMARY SMELTING PROCESS OF ZINC AND LEAD[2/]



5.3.1.3 Emission Sources

Thermal processes contribute most to the release of airborne cadmium emissions because cadmium has very low melting and boiling points (321°C and 767°C, respectively). Therefore, roasting, sintering, and reduction in the pyrometallurgical process would warrant the closest attention, as they probably would be responsible for most of the airborne cadmium emissions.

The roasting procedure, part of both the pyrometallurgic and electrolytic processes, is not considered a source of large cadmium emissions. Control technology used at roasting facilities is highly effective and allows almost no emission of cadmium into the air.[6/]

Sintering is considered the major potential source of cadmium emissions, and is done at all pyrometallurgical plants. Reduction of the sintered ore is considered a source of airborne cadmium only if the externally-fired horizontal retort is used, as this configuration is not conducive to particulate control. The last horizontal retort in U.S. production has been replaced, so that emissions from these facilities are no longer a problem.

Electrolytic processing is considered to be relatively free of airborne emissions. A minor potential source of airborne cadmium emissions does exist in the filtration which follows leaching.

5.3.1.4 Control

High efficiency control devices are employed at all zinc smelters. Roaster facilities at all smelters use fabric filters or electrostatic precipitators (ESP). Sintering emissions are also controlled with fabric filters or ESPs.[1/]

5.3.1.5 Emissions Estimates

EEA's estimates of the cadmium released into the air through primary zinc production have been compared with estimates from other sources. EEA's emission factors, with assumed control technologies, were derived from several sources and expressed in pounds per ton of zinc produced. Yost (1974), and Jacko and Nuendorf (1977) measured coking emissions of 2.24 pounds/ton of zinc throughput using stack sampling[4,5/] and atomic absorption (AA) analysis. Sintering with a cyclone produces emissions at a rate of 6.32 pounds/ton of zinc produced, while sintering with controls of a cyclone and an ESP releases 2.16 pounds/ton of zinc throughput.[5/] The vertical retort, at the particular plant where the stack tests were conducted, emitted 6.5×10^{-2} pounds/ton of zinc throughput.[5,6/] It should be noted that these particular test results, though highly accurate in both sampling and analysis, may not be typical. Vertical retorts, which produce high emissions, are uncommon in the U.S.; in addition, high zinc losses were a problem at the plant, due largely to the high temperatures in the coking operation which was volatizing zinc and thus, cadmium also. The Sargent (1975) study concluded that roasting emits negligible amounts of cadmium into the air. Sargent's other estimated emissions factors which EEA used include: 6×10^{-3} pounds/ton of zinc produced in a horizontal retort; 1.2×10^{-2} pounds/ton of zinc produced by the electrothermic process; and negligible emissions from electrolytic processes.[6/] Overall emissions rates varied between 1.43 pounds/ton of zinc and 2.96 pounds/ton of zinc.[5,7,8/] To calculate an emissions estimate, a factor of 2.5 pounds/ton of zinc produced for nonelectrolytic processes was estimated by weighting the atomic absorption stack sampling results more heavily than previous mass balances.

Production figures (1974) of 423,000 tons of zinc processed pyrometallurgically and 121,945 tons of zinc processed electrolytically were combined with the overall emissions factor to obtain EEA's emissions estimate of 529 tons yearly.

The preceding estimate compared favorably with others made previously and was very close to the GCA estimate of 500 tons/year.[2/] Mitre found that 619 tons of cadmium were released in primary zinc smelting,[11/] EPA estimates 644 tons of cadmium,[18/] and Sargent estimates 112 tons.[16/] The Sargent estimate is lower than others made because it assumes 95 percent or better cadmium collection efficiencies which are presently attainable.

The production at primary zinc smelters increased in 1976 for the first time since 1972.[9/] In the years between 1972 and 1976, production had steadily decreased. This may account for the variety of emissions estimates obtained. Both the Mitre and EPA estimates were made before this decline occurred. GCA's estimate was made during a low point and EEA's estimate, based on 1974 data, illustrates the effect of more recent emission factors.

5.3.1.6 Future Trends

Future emissions are not expected to increase over the next eight years, in spite of an anticipated substantial increase in capacity. Between 1967 and 1975, the zinc industry lost nearly 50 percent of its capacity due to environmental problems, rising costs, and scarce capital.[9/] In 1976, however, there was a small increase in zinc production (4.6 percent) over 1975 and projections for 1977 indicate a 9.6 percent increase in production over 1976.[9/]

The zinc market is expected to remain stable with no large decrease in use anticipated. There is a possibility of increased use of zinc by the steel industry, as the use of thinner gauge steel will create the need for increased corrosion protection (zinc-coated steel).

Domestic smelter capacity may increase through 1985. ASARCO had planned to open a 180,000 ton/year electrolytic plant in Kentucky during 1979,[9/]

but was forced to abandon its plans due to a declining zinc market. Given a favorable market, the ASARCO facility could still be built. If present industry expansion plans continue, 1,000,000 tons of zinc would be produced in the United States in 1985.[9/]

Increased construction of relatively non-polluting electrolytic zinc-processing plants has led EEA to conclude that cadmium emissions from primary zinc smelting will remain constant at 529 tons/year. This is a high estimate, as the nonelectrolytic plants now in operation will probably be phased out and replaced by cleaner electrolytic ones.

5.3.2 Primary Lead

Primary lead is a source of cadmium emissions, but does not contribute greatly to the production of commercial cadmium metal. Lead is produced in much the same way as zinc, therefore, only a brief discussion of the process follows.

5.3.2.1 Process

Roasting is usually the first step which the ore concentrate undergoes in the process of purification and metal production. However, this is not always done with the lead concentrate. More often, the sintering machine or electric furnace receives the lead sulfide ore concentrate directly. During the sintering process, the concentrates are combined with coal, lime and silica flux, then reduced to the lead metal. At a blast furnace, the ore is initially reduced to molten metallic lead and then removed as lead bullion at specific intervals.

Slag processing is more common in primary lead smelting than in zinc smelting. The slags are placed in a fuming furnace, brought to the proper temperature, and mixed with powdered coal which burns and volatilizes most of the zinc remaining in the slag. Any residual lead is also collected.

Figure 5-1 illustrates the processing of primary lead.

5.3.2.2 Emission Sources

As in zinc smelting, thermal processes are the cause of most emissions from lead smelting.

Roasting is not considered a pollution source, because it is a step which is often deleted from the process. When roasting is done, good control technology is employed. Sintering operations created most of the airborne cadmium emissions in lead ore concentrate processing. With the one exception, all plants use updraft sintering which is considered superior to other types. Reduction blast furnaces are also a source of cadmium emissions; however, all plants use extremely efficient particulate collection apparatus on the sinters and blast furnaces.

5.3.2.3 Control Technology

In attempting to control the emission of cadmium to the atmosphere several collection devices are employed in primary lead processing. Emissions from sintering and blast furnaces are usually controlled with a cyclone plus a baghouse or an ESP. A waste heat boiler plus baghouse or ESP is used with the reverberatory furnace. In handling material from any of the steps of the processes, a hood and a settling chamber, cyclone, ESP or baghouse is used to control emissions.[1/]

5.3.2.4 Emissions Estimate

The emissions of cadmium from lead processing are estimated to equal two tons/year. Using data from several sources,[2,7,8,10,11/] and emissions factor of 1.1×10^{-1} pounds/ton of lead produced was obtained, assuming 3.0 percent cadmium in the particulate emissions. With a 95 percent control efficiency, the factor was used with a production figure of 886,095 tons (1974)[9/] to arrive at the above figure. The estimate is

lower than those previously made (Mitre--555;[11/] EPA---163;[2/] GCA---65[2/]), as the previous estimates were based on mass balances of the amount of cadmium in the feed material, assuming no control or, at most, a 50 percent control efficiency. Based on the assumption of no control used in other estimates, EEA estimates emissions of 48 tons/year.

5.3.2.5 Future Trends

At present, the primary lead industry is slowly recovering from the depressed level of 1975 and is expected to recover to a production level of 790 thousand tons by 1985.[9/]

The major uses of lead include storage batteries, gasoline anti-knock additives, and pigments. The battery market is considered strong. A substantial increase in demand is due to the desire on the part of the consumer for a longer-lasting battery, which requires 20-30 percent more lead for each unit. There is a possibility that batteries with longer lives may lead to a depressed market by 1985.[9/]

The demand for lead by the gasoline industry is expected to drop sharply. This market, which usually accounts for 17-18 percent of the lead consumed, faces a reduction potential of 70 percent in demand over the next few years.[9/]

Modifications of the catalytic converter and internal combustion engines which would allow use of leaded gasoline are still under study. This could bring about increased demand for lead, but the feasibility still remains unclear. Lead in paint pigments accounts for approximately six percent of total lead production, an increase over the last several years.

At present, producers are hesitant to increase capacity because of environmental regulation uncertainty and, at this point production

equals only 87 percent of capacity.[9/] Therefore, growth is expected in a steady, slow manner. NSPS regulations are not likely to affect the lead industry, as no new construction is being considered for the near future. EEA projects that a total of two tons/year of cadmium will be released into the air as a result of primary lead processing by 1985.[9/]

5.3.3 Primary Copper

Copper production constitutes a source of cadmium emissions into the atmosphere, but the concentration of the cadmium in the ore is too low for economical recovery. Emissions from this source are generated in much the same manner as those from lead and zinc.

5.3.3.1 Process

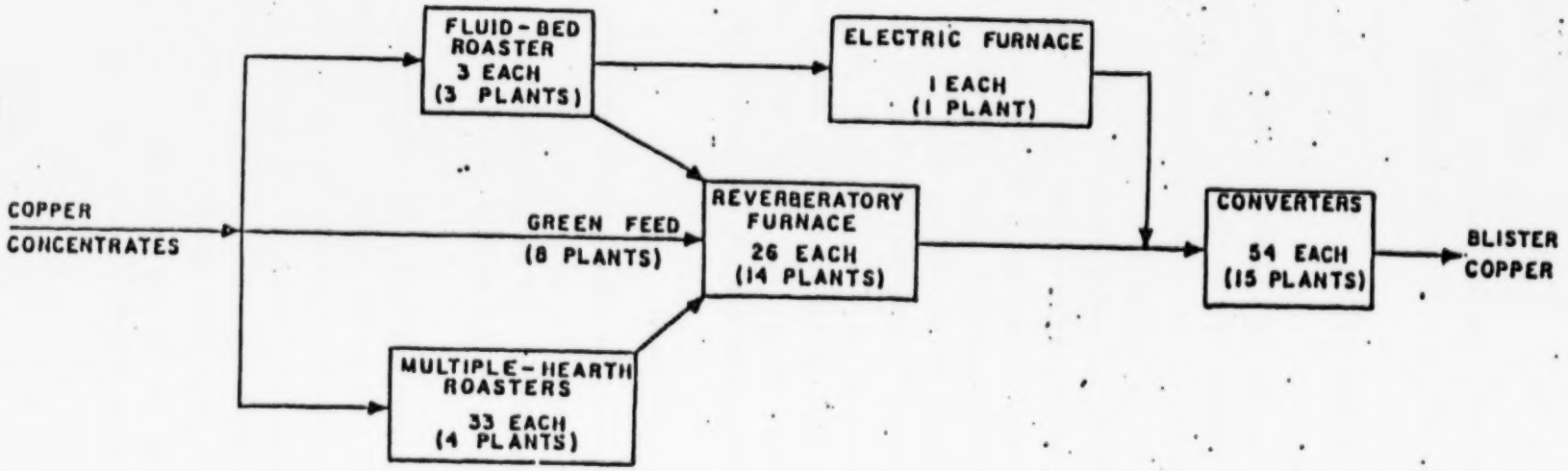
Ores which contain low percentages of copper are first subjected to a grinding and flotation process to produce a high percentage copper concentrate. The concentrate is then roasted to remove excess sulfur, and is placed in the reverberatory furnace. Here, a slag is formed through a combination of iron oxide and siliceous flux; a matte of copper, iron, and some sulfur is left. The convertor then reduces the matte to copper metal. To accomplish this, a stream of blowing air first eliminates sulfur. Then, a second stream of air reduces the copper sulfide to metal. At this point, the blister copper is refined further by fire-refining to reduce sulfur and oxygen, and the refined metal is then cast. (Figure 5-2.)

5.3.3.2 Emission Sources and Control

The thermal processes are again responsible for cadmium emissions. Roasting is considered a source of emissions in the copper production, and is usually controlled with a settling chamber, water spray, and some use of the ESP. Reverberatory furnace emissions are controlled with the ESP; converter emissions are controlled with settling chamber plus cyclones, and, at times, with an ESP. The settling chamber with cyclone

FIGURE 5-2

PRIMARY SMELTING PROCESS OF COPPER[2/]



is only good for larger particulates, therefore, control is not as efficient as possible at some smelting plants.

5.3.3.3 Emission Estimates

Primary copper production is a major source of atmospheric cadmium emissions. Two sets of emissions factors have been found, one for emissions from uncontrolled facilities, and one for facilities with the baghouse filter. In an uncontrolled smelter, emission factors range from a possible 7×10^{-2} pounds/ton of copper to 2.9×10^{-1} pounds/ton of copper.[2,7,8,10/] A best judgement figure of 1.5×10^{-1} pounds/ton of copper was developed from an average of five mass balance estimates. If all copper is produced without the use of control devices, 108 tons of cadmium would be released yearly. However, copper smelters employing baghouse control devices release only 7×10^{-3} pounds for every ton of copper produced.[2/] Five tons per year are emitted from these smelters. EEA's estimate for uncontrolled copper smelter emissions is very closely aligned to GCA's of 110 tons/year,[2/] while EPA[2/] and Mitre[11/] estimates equal 234 tons and 388 tons, respectively. Both these emissions estimates were made at earlier dates before certain data were available.

5.3.3.4 Future Trends

There are several possible applications which would create an increased demand for copper, and some technologies which will cause a decrease in copper consumption. The factors should combine to increase copper production to over 3.5 million tons by 1985.

The recent energy shortages have encouraged the development of solar energy applications and electric cars. In comparison to the conventional 1975 model car with 41 pounds of copper, the electric car is expected to contain about 200 pounds per car. Desalinization technology, which employs copper alloy tube, has become an industry of significance in countries such as Saudi Arabia. Fire sprinkler systems are becoming a required part of any new inhabited building, and this is expected to increase copper demand and production. An increasing use of electronics

in the telephone industry has reduced the use of copper conductors, and glass fiber optics will produce the same effect. Therefore, emissions of cadmium from primary copper production are expected to increase to 13 tons/year by 1985 in controlled smelters.

5.3.4 Cadmium

Unlike the other three metals discussed, cadmium is not mined, but rather is a by-product of other metal productions--primarily zinc. "Blue Powder," a part of the volatile product from zinc distillation, was at one time the major source of cadmium metal for commercial production. Most of the cadmium which is present in zinc and lead ore is now removed in earlier stages of processing.

There are several major sources of cadmium. Dust and fumes collected in the bag filters and ESP during roasting and sintering of the ores, and the cadmium and zinc filter cakes resulting from the purification of zinc sulfate solutions are two important sources.

Additional flue dusts, primarily from Mexico, are imported to meet consumption demands.

5.3.4.1 Process

There are two basic methods used to recover cadmium: one which serves to extract the metal from zinc ore roasting and sintering flue dusts, the other which extracts the metal from any leaching residues. Other processes are used to remove the metal from other flue dusts and slab zinc redistillation.

It is first necessary to insure that as much cadmium as possible is incorporated into the roasting and sintering flue dusts. This is done in one of two ways. In one, after roaster flue dusts have been returned to the roasted zinc ore concentrates, zinc chloride or sodium chloride

is added. Sinter-scalping, the second method used to concentrate cadmium in flue dusts, involving releasing the "top" part of the sinter to zinc smelting, and recycling the bottom part (where most cadmium is collected) through sintering.

These dusts are then usually processed for cadmium recovery, which entails several steps. First, the cadmium is treated with sulfuric acid to become cadmium sulfate. During this treatment, lead is precipitated, filtered, and sent to a lead smelter in the form of lead sulfate. Next, a sponge is formed by addition of acid and zinc dust to the cadmium sulfate solution. The sponge is then washed and dried, mixed with coke and distilled. The resultant vapor is condensed and cast into metal balls or ingots. Any distillation residues are directed back to the sintering process. The sponge can also be purified through treatment with a high-grade zinc dust and converted to molten cadmium metal by adding molten caustic soda. This process decreases airborne emissions when compared to the direct melting of sponge.

In electrolytic production, the cadmium loss to flue dust is not as great, so that the dusts must be returned to the roasted zinc ore before sulfuric acid treatment in order to ensure sufficient cadmium concentration. The resulting solution is then mixed with zinc dust to remove any copper and to produce a zinc-cadmium cake. This cake is often subjected to an air or steam treatment preceding a sulfuric acid and electrolytic treatment. The final cadmium sulfate solution is obtained by adding zinc dust to the cake to produce a cadmium metal sponge which, in turn, is redissolved in the electrolyte. This solution is then electrolyzed to metal, deposited onto aluminum cathodes, stripped from the cathodes, and melted to cast ignots.

Cadmium is also recovered from lead and copper ores, though this is not usually done. Generally, it is not an economical practice.

It is also possible to obtain cadmium from the redistillation of contaminated zinc slab. The distillation is a two-step process. First, the impure zinc is placed in a still at a temperature which distills the zinc and cadmium to be condensed in a second still, while the lead remains behind. The zinc-cadmium mixture is then distilled at a temperature such that the cadmium is vaporized, while the zinc remains in a molten form. The cadmium is then condensed and cast.

See Figure 5-3 for a flow diagram of cadmium recovery from the above processes.

5.3.4.2 Emissions Sources and Control

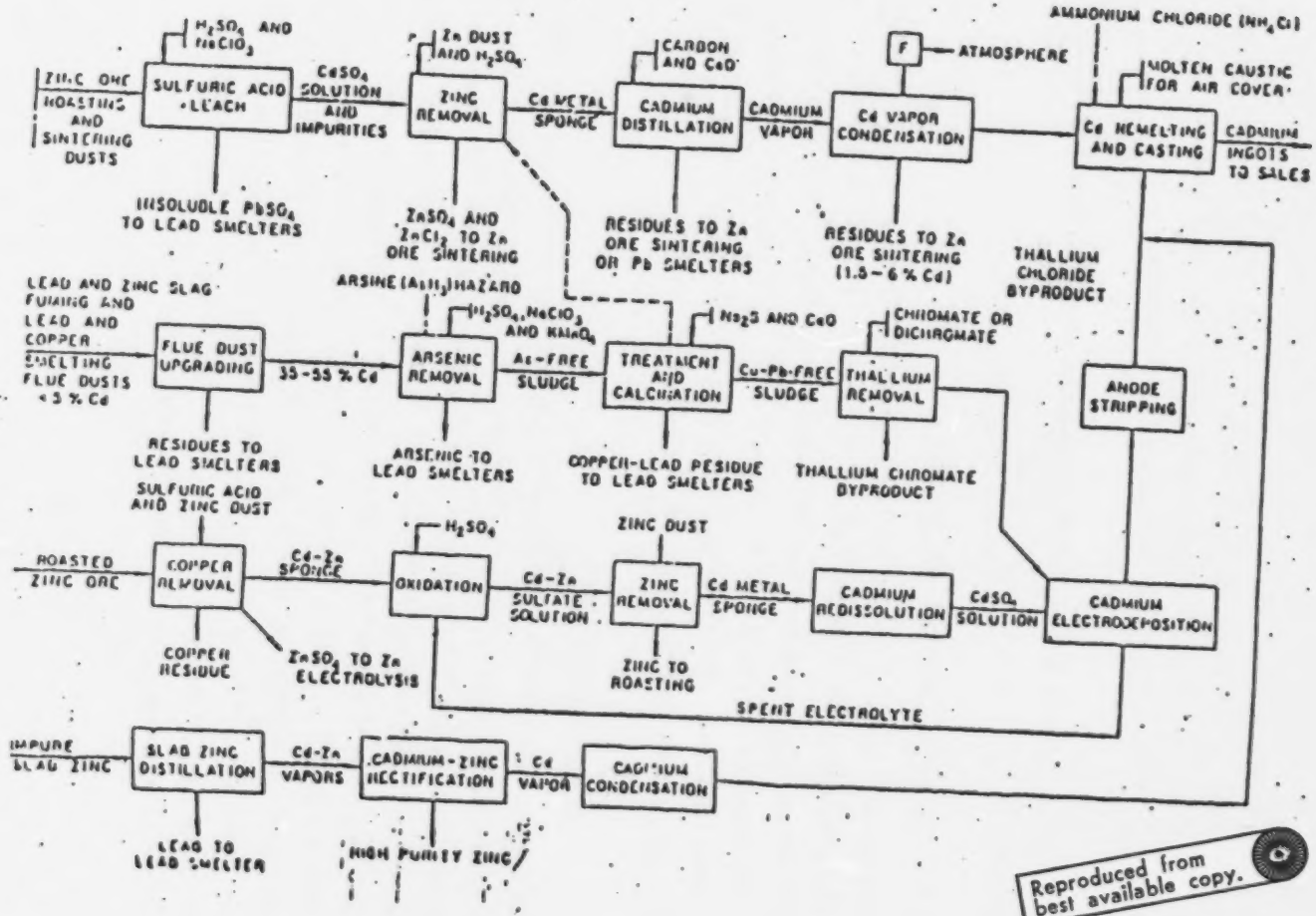
Emissions are again a result of the high temperature processes involved in the production of cadmium metal. Cadmium distillation and vapor condensation are major sources of cadmium emissions. Most cadmium purification processes are wet, so that many steps do not contribute to airborne cadmium. Most smelters employ high efficiency bag filters or ESP's as control devices to prevent cadmium emissions.[1/]

5.3.4.3 Emissions Estimate

EEA's emissions estimate is lower than estimates by the EPA and GCA due to EEA's use of current data on control technology. Emission factors ranged from 25 to 30.5 pounds/ton cadmium produced.[7,8,10/] A "best judgement" (the average of three mass balance estimates" of 28 pounds of cadmium produced was used, together with a 1974 production figure of 3,008.2 tons[12/] to reach the estimated emissions of two tons of cadmium emitted from facilities with a 95 percent control efficiency. EPA[2/] estimated that cadmium production resulted in 60 tons/year and GCA[2/] estimate is 50 tons/year. EEA's estimate of 43 tons/year, assuming no control, is comparable to these figures.

FIGURE 5-3

PRIMARY SMELTING PROCESS OF CADMIUM[2/]



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5.3.4.4 Future Trends

Cadmium production has decreased quite steadily in the past five years, from 3,760 tons in 1972 to 2700 tons in 1976.[12/] This is due, in part, to the decreased use resulting from environmental regulations and is closely associated with the drop in production of zinc. However, cadmium production is not expected to continue its downward trend, but rather to increase along with zinc production in the near future. At present, cadmium is used for a variety of items which will be discussed in the following sections. However, it is possible that the producers of solar energy equipment could become large consumers of the metal. Cadmium production is linked to zinc production and, therefore, is expected to increase at a similar rate. Emissions are projected at less than one ton/year by 1985.

5.4 IRON AND STEEL

The iron and steel industry releases relatively large amounts of cadmium into the air. These emissions are a result of the melting of cadmium-coated scrap, usually number two steel scrap.* Descriptions of the four major types of plants, including the sintering strand, the open hearth, the basic oxygen furnace, and the electric arc, are included with current industry trends. The blast furnace, which emits almost no cadmium, is excluded.

5.4.1 Sintering

The sintering plant receives two different materials which require processing. Beneficiation of very fine iron core and flue dusts is accomplished at the sinter plant and different iron-bearing materials become agglomerated at the plant. Sintering of the above materials ensures a higher iron content, lessens moisture, and often removes some sulfur. This renders the resultant product a more suitable feed for the blast furnace.

* Steel is often galvanized with cadmium to protect it from corrosion. When the scrap is melted, cadmium is emitted.

5.4.1.1 Process

To accomplish the sintering, a mixture of fine ore and powders of carbon sources, such as anthracite and coke breeze, are placed on a traveling grate. The grate moves over a series of windboxes where the mixture is lit with a burner. As air is pulled down through the ore with fans, the ore mixture burns, agglomerating the ore particles. The use of sinter aides the performance and productivity of blast furnaces.

5.4.1.2 Emission Sources

During the heating of the mixture of fine ore and other materials (blast furnace and other flue dusts), cadmium escapes into the atmosphere. Because the flue dust, and other such materials contain amounts of cadmium, any heating of this material causes cadmium to volatilize.

5.4.1.3 Control

Sinter strands employ one or more of three types of control devices. The cyclone is employed alone, or more often with a baghouse or ESP. In 1976, approximately 66 percent of the sinters used little or no control, while 34 percent employed at least one of the above methods.[13/]

5.4.1.4 Emissions Estimate

The estimate of airborne cadmium emissions emanating from the sintering process was developed from three sets of EPA stack sampling tests for which a semi-quantitative analysis technique, emission spectroscopy (ES), was used. Sampling runs had been taken for both controlled and uncontrolled sinter plants, so emission factors were developed for both. The uncontrolled emissions factor of 2×10^{-3} pounds/ton[14/] of feed indicates that approximately 22 tons of cadmium result from the production of 21.94×10^{6} tons of sinter.[13/] With a rotoclone plus ESP control, the sinter windbox tested had an average emission factor for two runs of

9.5×10^{-4} pounds/ton of feed.[14/] Assuming that this emission factor is representative of all controlled sintering operations, the total annual emissions of cadmium from these sources equal 5 tons yearly (11.35×10^6 tons of sinter[13/]). Total emissions (controlled and uncontrolled) from sintering equal 27 tons yearly.* EEA's emission factors, based on the windbox tested, imply a control efficiency of only 50 percent. Industry comments and stack data suggest that a 90 percent control efficiency may be attainable.[48,50/] If these estimates and stack tests are confirmed then industry-wide emissions would be much lower.

5.4.1.5 Future Trends

Sinter strand production is expected to increase slightly between 1974 and 1985. A decrease in production occurred between 1974 and 1975. However, by 1977, a recovery had been made and production increased slightly over 1974 (33.3 MM tons in 1974; 34.0 MM tons in 1977). Based on the historic growth rate, it is expected that sinter production will reach 40 million tons/year by 1985.[13/] However, sinter capacity will remain constant at 46.9 million tons[13/] through at least 1983. By 1985, it is expected that all facilities will be in compliance with control regulations, and all will employ some control device. On this basis, cadmium emissions from sintering are expected to equal 19 tons/year by 1985. This assumes a control efficiency of only 50 percent, which is unrealistic according to industry.[48,49/] Using an emission factor of 1×10^{-4} lb/ton of feed, which reflects 85 percent control efficiency, total 1985 emissions would amount to only about 2.3 tons. However, an accurate estimate of current or expected cadmium emissions is extremely difficult for two reasons. First the industry is upgrading existing control technology and even replacing existing types of technology with new types. Second the amount of cadmium released is a function of both the type (ore or millfines) and day-to-day variability of the feed.

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*Comparative emissions estimates will be discussed at the conclusion of the iron and steel section, as other estimates are not broken down by process.

5.4.2 Basic Oxygen

The basic oxygen process was developed and first used in the early 1950's. It has become a highly competitive form for producing steel and has replaced much of the open hearth production.

5.4.2.1 Process

The basic oxygen furnace is a cylindrical steel furnace, lined with refractory material, which has an opening at only one end. For charging and tapping the furnace vessel rotates around a lateral axis. Slag is retained in the furnace and is then tapped off by way of a tap-hole near the mouth of the furnace. The charge materials used in the basic oxygen furnace include hot metal from blast furnaces (70-80 percent), scrap, cold pit iron, and iron oxide.

In the process, the furnace is first tilted for the addition of scrap and hot metal. It is then brought to a vertical position. Next, an oxygen injection lance is placed in the furnace producing a reaction flame which is visible along the furnace mouth. Through an overhead chute, fluxes of lime and fluorspar are funnelled into the furnace causing the reaction flame to rapidly decrease. Temperature readings are taken and the refined metal and slag samples are analyzed after the carbon content reaches the desired level. Finally, the furnace is tilted to tap steel into a ladle.

5.4.2.2 Emission Source and Control

Emissions of cadmium result from the melting of scrap in the furnace. From the time the furnace is charged with the scrap, cadmium contained in the scrap is volatilized in the furnace.

The emissions from the basic oxygen furnace are controlled primarily by ESP's. However, approximately 40 percent of all controlled basic oxygen

furnaces use high energy venturi scrubbers to aid in the abatement of airborne cadmium emissions.[1/] Approximately 98.5 percent of all existing basic oxygen furnaces employ some type of air pollution control device.[13/]

5.4.2.3 Emission Estimate

To determine emissions resulting from the basic oxygen process, emissions factors were developed. For uncontrolled furnaces, an emission factor of 4.1×10^{-5} pounds/ton of steel was developed by assuming a reported concentration of cadmium in the particulate of 80 ppm and the AP-42 particulate emission factor of 51 pounds/ton of steel.[15/] Production of steel in these facilities equaled 1.2×10^{6} tons.[13/] The emission factor of 1.2×10^{-5} pounds/ton of steel for furnaces controlled by a venturi scrubber or ESP is the average for six EPA stack tests using analysis by emission spectroscopy.[14/] Production of steel at these facilities equaled 78.8×10^{6} tons.[13/] Emissions from this source are estimated by EEA to be less than one ton/year.

5.4.2.4 Future Trends

The basic oxygen furnace is considered to have a substantial growth potential through 1985. It is thought that as much as 75 percent of the 1985 steel production in the U.S. will be achieved through this process.[16/] Obviously, emissions will increase (to 1 ton/year); however, the source will remain one which does not produce over one ton of cadmium emissions each year.

5.4.3 Open Hearth

Open hearth production of steel has been decreasing steadily over the past ten years due to economic and environmental concerns. However, the process does account for 25 percent of the steel produced[16/] and is a source of cadmium emissions.

5.4.3.1 Process

A reverberatory type hearth furnace is heated alternately by a combustion flame from either end of the hearth. At regular intervals, the gas flow is reversed in order to recover sensible heat from the exhaust gases. This is accomplished by passing them through brick checkers which are at either end of the furnace. At each reversal, the brick checkers are hot enough to heat the incoming combustion air so that the high flame temperatures needed to melt and refine raw materials are more readily reached. The furnace is charged with scrap and heated to incipient melting by oil, gas, or tar flames which move across the top of the hearth. Hot metal is added to the furnace at this point. The next step involves addition of the necessary flux and oxidizing materials to refine the mix while it boils.

5.4.3.2 Emission Source

The cadmium is volatilized when the scrap is melted.

5.4.3.3 Control

Eighty percent of open hearth furnace capacity uses ESP's to control emissions, while 20 percent is without any kind of controls.

5.4.3.4 Emissions Estimate

Open hearth emission factors have been determined for both the controlled and uncontrolled operations. A "best judgement" estimate for uncontrolled furnaces of 5.78×10^{-3} pounds/ton of steel[5/] is determined to best represent estimates between 4.08×10^{-3} pounds/ton of steel and 6.48×10^{-3} pounds/ton of steel.[5/] The ESP control reduces emissions to between 2.08×10^{-5} pounds/ton of steel and 1.34×10^{-4} pounds/ton of steel.[5,15,17/] This recent series of stack tests using AA analysis has produced a "best estimate" of 1.1×10^{-4} pounds of steel. From this, and a production

figure of 29.06 x 10^6 tons,[13/] it was determined that controlled open hearth facilities contribute two tons of cadmium into the atmosphere each year. Uncontrolled emissions, with a production level of 7.64 x 10^6 tons,[13/] equal approximately 22 tons/year, resulting in a total of 24 tons of cadmium emissions yearly.

5.4.3.5 Future Trends

As has been stated, the open hearth is not environmentally and economically competitive with other steel-making processes. Since 1965, open hearth steel production capacity has dropped from 110.82 MM tons/year to 37 MM tons/year.[13/] It is expected to continue declining through 1985 to 21.1 MM tons/year.[13/] No new open hearth facilities are planned. Emissions, assuming that 100 percent of the open hearths will use some control device, are estimated to be about one ton/year by 1985.

5.4.4 Electric Arc

The electric arc furnace, the fourth method by which steel is produced, has enjoyed steady growth since its initial installment in 1906. At present, it accounts for the production of approximately 27.3 MM tons of steel each year.[13/] The process allows for the production of a large variety of objects and is flexible in operation, which accounts for its growing popularity.

5.4.4.1 Process

Steel scrap is the principal material used for feed in electric arc steel-making, while iron sponge is occasionally used as a portion of the feed. Scrap is processed in a furnace which is shaped like a cylindrical shell, shallow in depth, with a large diameter. A removable roof on the shell allows for the insertion of three graphite electrodes. High performance refractories completely line the shell and roof.

Steel-making is accomplished in a series of heats, each producing a certain tonnage of some form of steel. Each cycle begins when a partial charge is loaded into the top of the furnace, the roof is closed, and the electrodes are lowered into the furnace. The electrodes are placed so that the electric current produces an arc between them and the charge. After the melting of the partial charge, the remainder is added and melting continues to the end of the heat. The entire process usually requires three to four hours for completion. When the process is completed, the steel is placed in a transfer or teeming ladle, while the slag is dumped into a slag pit.

The process is used to produce a large number of different steel products such as structural steel, specialty alloys, tool steels, super alloys, and stainless steels.

5.4.4.2 Emissions Sources and Control

The melting process which the steel scrap undergoes in the electric arc produces cadmium emissions. Because the primary feed for the arc furnace is steel scrap, this process produces more cadmium emissions than any other steel production operations. (Sintering, with a slightly higher amount of cadmium emissions, is a raw materials processing operation). Control is accomplished with the use of a baghouse and the occasional use of a scrubber or ESP. Approximately 100 percent of all electric arc furnace capacity employs some method of control.[1/]

5.4.4.3 Emissions Estimate

It is estimated that the electric arc furnace emits 3.4×10^{-3} pounds of cadmium/ton of steel. This "best judgement" estimate was developed from estimates between 2.7×10^{-3} pounds/ton of steel and 5×10^{-3} pounds/ton of steel by assuming a particulate cadmium concentration of 735 ppm from EPA ES stack test results,[14,15/] and the AP-42 particulate emission factor of 4.6 pounds of particulate/ton of steel. Using this emission factor

factor, and a total production figure of 27.3 x 10^6 tons, EEA estimated that at a 90 percent control efficiency, cadmium emissions from this process equal approximately 5 tons/year.

5.4.4.4 Future Trends

The electric arc furnace is a steadily growing method of producing steel. The increase in the electric arc is a result of several factors which include the viability of the "mini-mill" concept, the applications possible for high-intensity arc furnace technology, larger amounts of scrap available due to growth of the basic oxygen furnace coupled with decline of the open hearth, and increasing economic viability of direct ore-reduction processes. Therefore, an historic growth rate was used to project that there will be an increase of about 11 MM tons produced by the electric arc through 1985. Emissions will increase somewhat; however, all electric arcs will be controlled in some way. NSPS standards will have some effect upon the process, because expansion of existing plants seems likely.

5.4.5. Total Iron and Steel Emissions

To compare EEA's iron and steel emission estimates with estimates of other studies, it was necessary to total all processes.

5.4.6 Total

EEA's emission estimate of 56 tons/year is not in agreement with most others (Davis--1,000;[7/] Mitre--1,000;[11/] EPA--78;[2/] GCA--400;[2/] and Sargent--11.5[6/]). The assumed control technology was based on the Temple, Barker, and Sloane steel study (1976),[13/] which was unavailable at the time previous estimates were made. Several emission factors were also based upon data previously unavailable. EEA assumed a higher degree of control technology and production figures could vary among the

sources. Therefore, the variation between estimates is not unexpected. Assuming that each individual process is entirely uncontrolled, EEA estimates a value of 146 tons/year for cadmium emissions. Previous estimates failed to consider processes individually, so that it is difficult to determine whether EEA's assumptions of control technology are comparable to those made in the previous aggregate estimates.

5.5 SECONDARY SMELTING

Secondary smelting processes involving zinc, lead, and copper are not viewed as large emitters of cadmium when each is viewed as an aggregate (all zinc smelters; all copper; all lead). Each metal will be dealt with individually in the following discussion.

5.5.1 Secondary Zinc

5.5.1.2 Process

Zinc can be melted, "sweated," or vaporized in processing. To recover the zinc from scrap, sweating is the most common procedure. The furnaces employed to carry out this process include rotary, reverberatory, and muffle furnaces. In zinc melting, the scrap is combined with ingot and rejects and is melted to create a molten bath. After light scrap is added to the bath, it is heated to the correct pouring temperature and poured. The zinc vaporization is carried out in retort furnaces to reclaim zinc from alloys and to recover zinc from its oxide (among other processes).

Distillation and muffle furnaces are used to separate zinc from the alloy which is then processed and converted to zinc metal.

5.5.1.3 Capacity

It is possible to obtain a total production figure for the industry (75,409 tons in 1974,[47/]) but no figures of individual plant capacity or production are available.

5.5.1.4 Source and Control

The source of cadmium emissions from all three processes is the melting of the material at high temperatures. In preparing the scrap material for charging, no control device is used or needed. Sweating furnaces are equipped with an afterburner and a baghouse, while distillation furnaces are equipped with baghouses. Only 20 percent of the sweating furnaces use control devices, while almost all distillation furnaces employ controls.[1/]

5.5.1.5 Emissions Estimate

Cadmium emissions from zinc secondary smelting operations are small. This is due to the fact that most of the cadmium has already been volatilized during primary smelting.

Uncontrolled emission estimates between 8×10^{-3} pounds/ton of zinc and 1.4×10^{-2} pounds/ton of zinc produced[8,10,18/] were found in the literature. A "best judgement" factor of 1×10^{-2} pounds/ton of zinc produced was then derived from the mass balances. The 1974 production figure was used to compute an emissions estimate of less than one ton of atmospheric cadmium resulting from the process yearly. EPA[2/] estimated emissions from this process to be two tons/year, as did GCA.[2/] Sargent combined all secondary non-ferrous metal processing to obtain an emissions estimate of 2.4 tons yearly.[6/]

5.5.1.6 Future Trends

Annual production of zinc through secondary smelting is expected to increase slightly through 1985 to 130,000 tons.[47/] There is no reason to assume a dramatic increase or decrease in production. Emission control will improve so that the increased production as a whole should not cause a large net increase in emissions. Cadmium emissions would thus increase slightly to about one ton/year.

5.5.2 Secondary Lead

5.5.2.1 Process

Secondary led smelting is a process from which cadmium emissions are derived. Lead automobile storage batteries, lead-sheathed cable and wire, aircraft tooling dies, type-metal drosses, and lead dross and skims are the materials most commonly sweated to obtain lead. To process materials which contain a small percentage of the metal, a rotary furnace or sweating tube is usually employed. A reverberatory-box type furnace is used when dealing with material of high lead content.

Blast furnaces are also used frequently in secondary smelting of lead storage batteries. Lead is charged into the furnace at the beginning of the operation in order to provide molten metal to fill the crucible. Limestone and iron flux float on the top of the lead to inhibit its oxidation. The molten metal is poured when proper conditions are reached.

5.5.2.2. Capacity

As with zinc, capacity of individual plants could not be obtained for this study. However, 1974 total production was 698,698 tons.[12/]

5.5.2.3 Emissions Source and Control

Airborne cadmium emissions emanate from the melting process during which cadmium is volatilized. The control measure used with both reverberatory and blast furnaces is generally a baghouse, occasionally in combination with an ESP.[1/]

5.5.2.4 Emissions Estimates

The amount of cadmium produced by secondary lead smelters has not previously been estimated. Emission factors for this process were developed from EPA stack testing results. Three factors for three different combinations

of furnace type and control technology were used to compute emissions estimates. However, because of difficulty in obtaining production data, the most conservative emissions factor of 2×10^{-6} pounds/ton of lead was used.[14/] Combined with the production figure for secondary smelters, the emission factors produce a relatively low estimate of total emissions (less than one ton).

5.5.2.5 Future Trends

The production of secondary lead is expected to increase through 1985. It is felt that the growth of this sector of the lead industry will largely account for the growth of the entire industry. However, until the long-term effects of both the OSHA regulations and EPA rulings are determined, secondary producers will be reluctant to increase capital expenditures for new plants and equipment. This indicates that the impact of NSPS will be minimal at best. Emissions are expected to increase, but remain under one ton/year.

5.5.3 Secondary Copper

Scrap serves as the primary feed for most secondary copper operations. The scrap received usually contains many impurities including cadmium. During the processing, which is discussed below, these impurities are removed and copper metal is cast for re-use.

5.5.3.1 Process

Scrap can be processed mechanically or by a pyrometallurgical process. At medium temperatures, sweating removes metals which have a low melting point. Burning removes insulation which was not removed mechanically from copper wires. To remove excess cutting fluids from machine shop chips and borings, vaporization occurs in a heated rotary kiln. The blast furnace produces a product called "black copper" which is a concentrated

material. Concentration is accomplished by taking scrap and charging it at the top of a vertical furnace together with coke, a reducing agent, and a fluxing material. The concentrated material plus some slag are drawn out at the bottom of the furnace.

After the scrap is processed it undergoes smelting and refining, melting, and alloying in a variety of furnaces, including the reverberatory, the rotary, or the crucible. The choice of one over the other is dependent upon the quantity of scrap to be melted and the type of alloy to be produced. The reverberatory and rotary furnaces are direct-fired furnaces in which the hot, high-velocity combustion gases are in direct contact with the metals in the charge. Thus, it is difficult to effectively capture the emissions from these types of furnaces with a hood.

During charging, all the scrap material is usually not placed in the furnace at once due to the large quantities involved. After charging, the melting occurs. The burners are set to ensure a very rapid melt-down, and additional oxygen may be added at this time. Refining, the next process which the metal undergoes, involves fluxing the molten bath of metal to cause selective oxidation. In alloying, virgin metal or specialized scrap may be added to modify the final product of the melt. The last step is pouring the molten metal from the furnace into a mold. This can be done by tapping the furnace directly to an automated mold line, or into a ladle from which it is transferred to a mold line.

5.5.3.2 Source of Emission and Control

Almost all processes in secondary copper smelting produce some emissions of cadmium. Sweating involves a very small loss of metal fume. Burning the insulation from copper wire may be a minor source of cadmium emissions, but no data has been found to substantiate this. However, the rotary kiln, which vaporizes copper and cadmium, can cause a large amount of emissions. Usually afterburners are employed to complete combustion and

decrease emissions. The combustion processes which result in air-borne cadmium emissions include those involving the blast furnaces, direct fire furnaces, charging, melting, refining, and alloying. During wire burning no control devices are employed. However, in sweating, an afterburner and baghouse are used. The blast furnace is equipped with a baghouse, while the reverberatory and rotary furnaces both are equipped with a hood and baghouse.

5.5.3.3 Emission Estimate

Approximately 38 tons of cadmium emissions result each year from secondary copper processing. Emission factor estimates range from a minimum of 2.6 pounds/ton of copper scrap to a maximum of 4.0 pounds/ton of copper scrap.[28/] The factor used (three pounds/ton of copper) is the average of two mass balances. A 1974 production figure of 513,308 tons of copper was also used.[12/] EEA's estimate is lower than that which have been made up to this point except one (Davis--125;[7/] Mitre--125;[11/] EPA--65;[2/] GCA--70[2/]). This is because a greater number of control devices and a greater efficiency of control were assumed by EEA (95 percent particulate control efficiency for the nearly universally employed baghouse). The Sargent figure of 2.4 tons of cadmium released per year from secondary non-ferrous metal processing is lower than any of the others.[6/] Using a collection efficiency of 90 percent, EEA's estimated emissions of 77 tons are comparable to other estimates, especially those of EPA and GCA.

5.5.3.4 Future Trends

The Bureau of Mines predicts that production of secondary copper will increase five percent each year to 1985.[20/] Using 1975 as a base, this would mean 836,000 tons of secondary copper would be produced by the industry in 1985. Emissions would also increase substantially through 1985 to 62 tons.

5.6 MANUFACTURING

The production of paint pigments, plastic stabilizers, and nickel-cadmium batteries results in cadmium emissions into the air.

5.6.1 Cadmium Pigments

Cadmium compounds, principally the sulfides and sulfoselenides, are used as coloring agents in paints and plastics. The sulfide compounds are used to impart colors of yellow to orange, while sulfoselenide colors range from light red to dark maroon.

In order to "stretch" the pure cadmium pigments, white barium sulfite is often mixed with the pure pigments to create "cadmium lithopones."

5.6.1.1 Process

The use of these pigments is widespread due to their stability in light at relatively high temperatures in various chemicals, in various weather conditions, and in moisture. This makes the use of the cadmium pigments in plastics, which require high temperature molding, extremely practical. Other uses include artist's colors, rubber, and printing inks.

The preparation of these pigments does cause release of airborne cadmium emissions. By heating cadmium and sulfur ($Cd + S \xrightarrow{Heat} CdS$), cadmium sulfide is produced. It can also be made by precipitating an aqueous solution of soluble cadmium salts and soluble sulfides or H_2S. Color variations (yellow to orange) are produced when the temperature of the H_2S solution is altered (a cold acid solution yielding yellow, and the hot solution producing orange). In preparing cadmium sulfoselenide pigments, selenium is added to solutions of barium salts. This solution is, in turn, reacted with $CdSO_4$. To remove any unreacted selenium, the final product is calcined with excess sulfur. Each of the above processes must contain a calcination, or drying step. Without calcination, the pigments would not be dry and would be impossible to compound.

5.6.1.2 Emissions Source and Control

Any loss of cadmium to the environment during the manufacture of cadmium pigments originates from the dust which is produced during calcination. However, all facilities which are involved in pigment production have installed baghouses to minimize emissions.

5.6.1.3 Emissions Estimate

The emissions factor used to calculate cadmium emissions was the mass balance estimate developed by Davis[7/] and cited by Anderson.[8/] A factor of 15 lbs/ton of cadmium charged is suggested as the emission factor for this process. With production of 1,212 tons in 1974,[6/] nine tons of cadmium/year are released into the air. Davis, Mitre, and GCA all estimate emissions from this process to be 11 tons/year. The estimates of seven tons/year by the EPA and 9.5 tons/year by Sargent are in closer agreement with EEA's than other figures.

5.6.1.4 Future Trends

The use of cadmium pigments is expected to increase slowly during the near future to 1,560 tons, which will slightly increase emissions from this source (12 tons). Substitutes for cadmium pigments are available (zinc, lead, and barium chromates). The yellow cadmium-based dye used in printing inks has proven extremely difficult to bleach on paper recycling operations. However, it is expected that cadmium pigment production will steadily increase.

5.6.2 Plastic Stabilizers

In order to protect plastics from degradation by heat and light, it is necessary to add stabilizers to them, especially to PVC and related polymers. Most plastics which are destined for use outdoors are stabilized in this manner.

5.6.2.1 Process

Stabilizers must counteract the loss of acid, usually HCl, by the PVC because this is usually the first step in degradation of the plastic. Cadmium stearates, which are long, straight-chain organic esters, will react with the HCl to produce weak organic acids and ionized cadmium chloride. When used with no other additives, this stearate successfully lends the desired heat and light stability to the plastics. When combined with barium compounds, epoxides, or organic phosphates, the stearate is even more effective. Because it is the least expensive of the available cadmium plastic stabilizers, it is also the most popular. Other compounds used include cadmium laurate and cadmium recinoleate.

5.6.2.2 Emission Sources and Control

Any airborne cadmium emissions which result from the processing of plastic stabilizers originate from the handling of pulverized cadmium oxide. The cadmium oxide is used to prepare cadmium soap or other organic stabilizers. The procedure involving the mixing of the prepared compound with the plastic is not believed to produce any appreciable emissions. All cadmium stabilizer producers use baghouse to control the emissions resulting from the process.[1/]

5.6.2.3 Emissions Estimate

It is believed that the stabilizer industry is responsible for very little of the total cadmium in the air. Using an emissions factor of six pounds/ton of cadmium charged[7,8/] developed by EPA from a mass balance analysis, and a 1974 production figure of 991.8 tons, EEA estimates that three tons of cadmium/year are released into the air in the production of stabilizers. Other estimates, including those made by Davis, Mitre, and GCA agree with that of EEA, while EPA[2/] estimates one ton of cadmium a year from the stabilizer process and Sargent[6/] estimates a release of 2.9 tons yearly.

5.6.2.4 Future

Because of ever-increasing FDA bans on the use of the cadmium compound in plastic stabilizers, particularly for use in plastic food wrappings, an almost constant annual production is projected for this product.[21/] Although figures show a slight increase (due to a small market recovery after 1973-1974), emissions are estimated to increase only slightly through 1985. The development of a calcium-zinc stabilizer, which can equal cadmium stabilizers in performance and cost, has also caused a decrease in the use and production of the stabilizer.

5.6.3 Batteries

The nickel-cadmium battery is perhaps the only product from which cadmium is recovered. Developed prior to 1900 by Jungar, it is superior to other batteries in efficiency and longevity. However, during processing, relatively small amounts of the material are released into the air.

5.6.3.1 Process

The "pocket" electrode is used most frequently in the nickel-cadmium battery to form the cadmium plate. This electrode is produced by pulling active materials (cadmium sponge) into perforated pockets on a nickel steel frame. Active materials, such as the cadmium sponge, react with the electrolyte solution of the battery to produce a charge.

There are two methods used to prepare the active materials. In one, powdered cadmium or a cadmium compound is dry-mixed with an expander, often iron, and then inserted into the pockets. Electrolytic coprecipitation of cadmium and iron from an acid electrolyte also produces an active material to be inserted into the electrode. This process requires filtering, washing, drying, ball-milling, and blending of the precipitate to produce the final product. The electrodes are then filled with one of the mixtures by insertion of machine-made brickettes or loose dust. To prevent dusting during this process, petroleum oil is often added in small amounts.

Recently, plates which have the cadmium deposited into them have been used successfully in cadmium-nickel batteries. The production of the plate can occur in four ways, all of which involve depositing cadmium, cadmium oxide, or cadmium hydroxide onto a nickel screen or onto a porous nickel plaque. The methods to accomplish this include:

- Soaking the plate in cadmium formate solution prior to thermal decomposition in air,
- Electro-deposition from a solution of a soluble cadmium salt, most often nitrate,
- Soaking in cadmium nitrate solution prior to reduction in an atmosphere of hydrogen, and
- Forcing a paste of active material into the nickel support.

At some point, either after or before the battery is assembled, the electrodes are subjected to the "formation" treatment. This entails submitting the electrodes to several charge-discharge cycles. This serves to remove impurities and loose particles.

5.6.3.2 Emissions Source and Control

There are several potential sources of airborne cadmium emissions from the production of the nickel-cadmium battery. All procedures which involve dry powdered cadmium and cadmium compounds, and the reduction and thermal decomposition steps which require high temperatures contribute to the emissions. During production of action materials, cadmium is released into the air. With adequate control, however, this industry should not prove to be a source of a large amount of airborne cadmium. Controls used by this industry are unknown at this point, both in kind and number.[1/] Adequate techniques, such as baghouses or ESPs, are available to the industry but are considered to be extremely expensive.

5.6.3.3 Emissions Estimate

EEA estimates that, based upon a mass balance emission factor of two pounds/ ton of cadmium charged,[7,8/] and a 1974 production figure of 628.14 tons,[6/] approximately one ton of emissions per year is released by the process. With the exception of Sargent (0.7 tons/year),[6/] all others did not report a specific emissions estimate from battery production.

5.6.3.4 Future Trends

The EPA estimates that the amount of cadmium used in batteries in 1985 will increase between 15-20 percent,[6/] while the Bureau of Mines predicts only small increases.[6/] The large increase predicted by EPA is based upon several factors. These batteries are also used in calculators and portable garden, power, and hobby tools, all of which are expected to increase in demand due to relatively low prices and increasing popularity.

EEA's estimated future emissions from the production of nickel-cadmium batteries are based on a projected annual increase of 15 percent and indicate that approximately two tons/year may be released from this industry.

5.7 FOSSIL FUEL COMBUSTION

Cadmium is found in fossil fuels, and therefore, these fuels are a potential source of cadmium emissions. It has been determined that coal-fired and oil-fired power plants, fuel oil, diesel oil, and gasoline are all responsible for some airborne cadmium.

5.7.1 Coal-Fired Power Plants

The coal-fired power plant represents a source of cadmium air emissions which is small unless the fly ash is not collected.[21/]

5.7.1.1 Process

To produce power, steam is generated using a fossil fuel. The fuel and a stream of air which has been preheated are directed to a furnace or a series of burners where combustion occurs. Because the process is not carried out under perfect conditions, incomplete combustion usually results. Incomplete combustion and the incombustible nature of some fuel constituents cause pollutants, such as fly ash, to be generated by the process. The heat from the combustion chamber heats water which is contained in a series of pipes in a boiler and generates steam.

5.7.1.2 Source of Emissions and Control

Emissions of cadmium particulates from coal-fired power plants originate from coal combustion. Impurities which exist in the coal, such as cadmium, are volatilized and condense on the particulate matter or fly ash. Devices used to control the emission of fly ash include ESP's and fabric filters.[1/] Approximately 97 percent of the coal-fired power plants employ one of the above control devices.[1/]

5.7.1.3 Emissions Estimate

The emissions from coal-fired power plants were estimated using emission factors developed from stack test results reported in several sources and the total coal consumed by such plants. These stack tests resulted in factors ranging from 1×10^{-4} to 1×10^{-1} pounds/ton of coal (uncontrolled)[14,22,23/] and from 1×10^{-6} to 7×10^{-4} pounds/ton of coal (controlled with ESP).[2,8,10,14/] The wide range of these factors is due largely to the variation in cadmium content of the coals burned. Best estimate factors were developed by taking geometric means of the stack tests. It was found that the emissions due to uncontrolled coal-fired power plants burning 3.913×10^{8} tons of coal,[42/] with an emissions factor of 1×10^{-3} pounds/ton of coal, equal approximately 196 tons. If all facilities were controlled with an ESP or its equivalent, an emission

factor of 6×10^{-5} pounds/ton of coal would be used together with the tonnage to estimate that 12 tons of cadmium would be released yearly. The controlled estimate is much more likely, as nearly all coal-fired power plants employ high efficiency particulate control equipment. Other emissions estimates have treated fossil fuel combustion in total. Thus, a comparison will be made on the basis of total emissions.

5.7.1.4 Future Emissions

Studies indicate that coal will become a more important source of power in the near future, and its use will increase, especially if the National Energy Plan is implemented. Therefore, uncontrolled emissions from this source will become greater, however, with increased control and improved technology, emissions will increase only slightly.[24/]

5.7.2 Oil-Fired Power Plants

Oil-fired power plants are similar to coal-fired power plants in terms of process and emissions. These plants produce a slightly smaller amount of cadmium air emissions than the coal-fired variety.

5.7.2.1 Process

For a description of the steam generation process, refer to coal-fired power plants. The major difference between coal- and oil-fired plants is that the firing mechanism and equipment required for oil are greatly simplified.

5.7.2.2 Emissions Source and Control

Thermal processes are responsible for the cadmium emissions in almost every source, and oil-fired power plants are no exception. The combustion of oil to create steam releases small amounts of cadmium impurities into the air. Ninety-nine percent of oil-fired power plants are controlled with cyclones.[1/]

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5.7.2.3 Emissions Estimate

The emission factor derived from EPA's emissions test results using ES analysis is 9×10^{-7} pounds/gallon for a plant with ESP control.[14/] The range of estimates fell between 7.1×10^{-7} and 4.4×10^{-6} pounds/gallon. Combined with an oil usage figure of 2.072×10^{10}/gallon,[42/] this produces an estimated nine tons of cadmium a year resulting from oil-fired power plants.

5.7.2.4 Future Trends

Although oil is expected to increase in price and become increasingly difficult to obtain, usage in the next few years is expected to continue to rise.[24/] Emissions are projected to rise to approximately 14 tons/year.

5.7.3 Other Fuel Oil Combustors

Fuel oils, including residual and distillate fuels, are used in various boilers or burners to supply heat to the residential, commercial, and industrial sectors. The process of operation is similar to the combustion which occurs in the boiler of an oil-fired power plant, but usually on a much smaller scale.

5.7.3.1 Emission Source and Control

The incomplete combustion of the oil and the impurities in the oil result in emissions of various kinds, including cadmium. There are no controls on these sources of cadmium emissions.[1/]

5.7.3.2 Emissions Estimate

Estimates of cadmium emissions indicate that heating oil is not a large source. An emissions factor of 3×10^{-6} pounds/gallon[14/] for residual fuels was developed as an average of six reported cadmium concentrations in the fuel, assuming that all cadmium was emitted. Distillate fuel

emissions were calculated using the diesel oil emissions factor of 7 x 10^{-7} pounds/gallon of oil consumed, which is a best judgement figure based upon factors ranging from 6 x 10^{-7} pounds/gallon to 2 x 10^{-6} pounds/gallon.[8,10,18,21/] Residual fuel consumption equaled 321.2 x 10^{6} barrels, and distillate fuel consumption equaled 613.9 x 10^{6} barrels.[39/] The resulting 1975 emissions are 9 to 20 tons for distillate and residual fuels, respectively.

5.7.3.3 Future Trends

The future consumption of heating oil will rise slowly through 1985 to 980.9 x 10^{6} barrels.[46/] To determine residual and distillate usage, proportions were assumed to be equal to those of 1975. Of total fuel consumed, residual fuel accounted for 34 percent and distillate for 66 percent. Total emissions are 31 tons/year based on consumption figures of 647.4 x 10^{6} barrels of distillate fuel and 333.5 x 10^{6} barrels of residual fuel in 1985.

5.7.4 Diesel Oil

5.7.4.1 Process

Diesel oil, which is burned in the diesel engine, is used by some automobiles, trucks, and other motor vehicles. An unregulated flow of air is fed into the engine and mixed with the fuel. This mixture reaches the cylinder or combustion chamber, is compressed, and then ignited. The injection of the highly-pressurized gases into the cylinder causes a sudden reduction in pressure, in turn, creating air temperatures which cause the ignition. The energy of the burning mixture moves the pistons, and the pistons' motion is transmitted to the crankshaft that drives the vehicle. The burned mixture then leaves the car through the exhaust pipe.

5.7.4.2 Emission Source and Control

The emission source is the thermal process which causes combustion of the oil itself. The emissions are actually released through the exhaust pipe, which accounts for almost 100 percent of the diesel engine's emissions. Control of cadmium emissions from this source is not practiced.

5.7.4.3 Emission Estimate

Diesel fuel oil emits cadmium at a rate of between 6×10^{-7} pounds/gallon and 2×10^{-6} pounds/gallon.[8,10,18,21] A best judgement figure, which assumes the emission of all the cadmium in the fuel (as measured by ES), is 7×10^{-7} pounds/gallon. With a consumption figure of 11,179,686 x 10^3 gallon,[39] and the "best judgement" factor, EEA estimates that four tons are emitted each year.

5.7.4.4. Future Trends

Diesel oil consumption is expected to rise to approximately 15×10^9 gallons by 1985.[38] Emissions from the combustion of the fuel are estimated to slightly increase to 5 tons/year.

5.7.5 Gasoline

To complete the discussion of fossil fuels which release cadmium emissions during combustion, gasoline must be considered. The process which actually releases the cadmium is the combustion of gasoline within the engine. Therefore, a brief discussion of this will be included.

5.7.5.1 Process

In the conventional automobile engine, a mixture of fuel and air is fed into a combustion chamber, or cylinder, by the carburetor, compressed, and then ignited by a spark from a spark plug. The pistons are put into motion by the energy released from the burning mixture. Also released are certain particulates, including cadmium. The emissions pass out of the car through the exhaust system.

5.7.5.2 Source of Emissions and Control

The source of emissions, as noted above, is the actual burning of the fuel which causes the volatilization of cadmium. Although it is possible that gasoline detergents leach cadmium from engine parts with which the gasoline has contact, no data has been found to support the possibility.

5.7.5.3 Emissions Estimate

The emission estimate for gasoline is based on an emission factor of 2×10^{-8} pounds/vehicle mile traveled in one year. This factor assumes that all the cadmium in the fuel is emitted and that the vehicle operates at 15 miles/gallon. This best judgement factor was obtained from literature which listed emission factors between 6.3×10^{-11} pounds/VMT to 4.5×10^{-8} pounds/VMT.[25,26,27,28,29] Total vehicle miles traveled by cars and motorcycles is estimated at $1,330,074 \times 10^{6}$ [43] producing estimated aggregate cadmium emissions of 13 tons/year.

5.7.5.4 Future Trends

It is expected that vehicle miles traveled will steadily increase in the coming years.[30] Even though vehicle miles traveled are expected to increase, emissions are not projected to substantially increase more than four tons/year to 1985.

5.7.6 Summary

EEA estimates that the five fossil fuel combustion processes release a total of 67 tons of cadmium into the atmosphere each year, assuming controlled coal-fired power plants. This figure is lower than estimates by GCA (250 tons/year);[2] EPA (198 tons/year);[2] and Sargent (130 tons/year),[6] due to more stringent control technology assumptions. Assuming a lower (90 percent) control efficiency for coal power plants, an additional 8 tons of cadmium would be emitted.

5.8 MISCELLANEOUS

Several cadmium emission sources contain very small amounts of cadmium which are not intentionally part of the product. Fungicides, phosphate fertilizers, rubber tires, and cement all contain cadmium. Release of cadmium emissions from these sources occurs in both the production and use of the products.

5.8.1 Fungicides

The type of fungicide which is used primarily on golf courses contains a small amount of cadmium. When the fungicides are applied to the courses, usually in liquid form, some cadmium loss is experienced. This loss is dependent upon several factors, including spray particle size and atmospheric conditions.

5.8.1.1 Emissions Estimate and Control

Emissions from this source are minimal (less than one ton/year). In order to develop this estimate, a production figure of 59,800 tons[9/] was combined with an estimated emission factor of 1×10^{-5} pounds/gallon.[7,8/] No control devices are used in the application of fungicides.

5.8.1.2 Future Trends

Future growth in production of this product is difficult, if not impossible, to project.[9/] Many factors enter into the future of fungicide production. Leisure time is increasing, and "planned" communities which include recreation facilities are becoming popular places in which to live. This would indicate that production would increase as more golf courses would require fungicides. Fungi may become immune to cadmium-containing fungicides, which would force a change in the type of fungicide used. This would cause a decrease in emissions. Each year many variables, including weather conditions and infestation rate, also affect the use of the fungicides. EEA has used an historic growth rate to determine that emissions from fungicides will not increase greatly through 1985.

5.8.2 Fertilizers

Phosphate and superphosphate fertilizers also contain a small amount of cadmium. Associated with phosphate rock is a small number of impurities, one of which is cadmium. The cadmium remains with the phosphorus in processing and becomes a contaminant in both phosphate and superphosphate fertilizers.

5.8.2.1 Emissions Source, Control and Estimate

The cadmium emissions are released during application of the fertilizer, but not during processing of the material. There are no control methods employed, as there is an inadvertent loss of the material. The emissions estimate is based upon an emissions factor of 2×10^{-4} pounds/ton for superphosphate fertilizer (from an EPA estimate),[6,8,31/] coupled with the production figure of phosphate and superphosphate fertilizers which equals $8{,}535 \times 10^{3}$ tons.[9/] The cadmium emissions from both phosphate and superphosphate fertilizers are a small portion of the total emissions (about one ton). Other estimates include those by Davis,[7/] GCA,[2/] and Sargent,[6/] which are all under one ton.

5.8.2.2 Future Trends

The future of phosphate and superphosphate fertilizers is uncertain in much the same way as that of fungicides. The industry experienced moderate increases in 1977 after lows in 1974-1975.[9/] In 1974 phosphate fertilizers were unavailable due to low production, while in 1975 pricing prevented farmers from making use of the fertilizer. Farmers who had done without the fertilizer in the previous years because of high prices found that a decreased use of fertilizer did not decrease crop yield.[9/] In 1976, production decreased due to oversupply in 1975 (addition of 1.5 million ton capacity plant) and decreasing use.[9/] Growth of the industry will be slow to moderate. With a 4.5 percent annual increase, based on

the 1976 consumption of 9,258 x 10^3 tons, 1985 emissions will remain at approximately one ton.

5.8.3 Rubber Tire Wear

Rubber tire wear is believed to be a source of several types of gaseous and particulate matter emissions, including cadmium. The curing process in the rubber industry employs zinc oxide as an activator through which the cadmium enters rubber processing. As the tires are worn down during use, cadmium is released into the air. There are no controls employed. Several sources were used to estimate an emission factor of 8 x 10^{-9} pounds/VMT, assuming a mix of the types of rubber with various cadmium contents in the tire population.[6,7,8,10/] Using total vehicle miles, 1,330 x 10^9, traveled per year,[39/] it was determined that rubber tire wear contributes a small amount of cadmium to the atmosphere (five tons/year). As mentioned in the discussion concerning gasoline, vehicle miles traveled will increase, causing emissions from rubber tires to increase.[30/]

5.8.4 Motor Oil Combustion

Motor oil combustion also contributes to cadmium emissions. Some oil is burned in the engine causing volatilization of cadmium and its release into the air. No emissions control is practiced. The emission factor 2 x 10^{-9} pounds/VMT, reported by Anderson (1973)[28/] and Deane (1976),[2/] coupled with vehicle miles traveled for passenger cars only (1,028,121 x 10^6),[43/] indicates that the combustion of motor oil does not contribute large amounts of cadmium into the air (one ton/year). In estimating future cadmium emissions from this source, the same projection used for gasoline and rubber tire wear was employed and indicates that through 1985 emissions from this source will increase only slightly.

5.8.5 Cement Plants

In the manufacture of cement, cadmium is released in rather small amounts. Cement is a non-metallic mineral product composed principally of lime and silica, with alumina and ferric oxide acting as fluxing materials.

5.8.5.1 Process

Cement is produced in one of two ways, either by the wet process or the dry process. The four basic steps in the production process include quarrying and crushing, grinding and blending, clinker production, and finish grinding and packaging.

The materials which enter the kiln at the top end are dried by combustion gases which are passed through the kiln counter-current to the materials. The revolving of the kiln causes the raw materials to fall toward the clinkering zone as the carbon dioxide is removed from the calcerous material (the material containing calcium carbonate which is the major constituent of limestone). After the partially-fused production clinker is cooled in the clinker cooler, gypsum or water is added and the mixture is ground in a ball and tube mill to the necessary fineness.

5.8.5.2 Emission Source and Control

Limestone, which serves as a raw material in cement production, contains a small amount of cadmium and when it is processed, cadmium is released. Control measures used to prevent cadmium from becoming an airborne pollutant include cyclones, with or without ESPs, and baghouses.[1/]

5.8.5.3 Emissions Estimate

There are many emissions factors which apply to the various methods and steps of producing cement as determined by EPA ES stack testing. In estimating emissions, the most conservative dry process factor was used by EEA because an increasing number of plants are using the dry process. An emission rate of 2.6×10^{-6} pounds/ton of feed,[14/] together with the appropriate production figure of $81{,}210 \times 10^{3}$ [9/] indicated that less than one ton of cadmium a year is released from the cement process. Previous studies have not estimated emissions from this process.

5.8.5.4 Future Trends

The production of cement decreased between 1974 and 1975 due to several plant closings and slow housing starts. However, in 1976, home construction increased. Although there has been little plant expansion or construction of new plants, it is felt that an annual (compounded) rate of 3.2 percent growth will continue through 1985.[32/] Because no new plants are planned, NSPS will not affect emissions, which, notwithstanding the increased production, will remain well below one ton.

5.9 INCINERATION

Incineration is a source of cadmium emissions due to the cadmium in the materials burned. These materials include plastics which contain cadmium stabilizers, objects painted with a cadmium-pigmented paint, and scrap metal coated with cadmium. Both municipal incinerators and sewage sludge incinerators emit cadmium into the air.

5.9.1 Municipal Incinerators

The municipal incinerator is a major source of airborne cadmium emissions, emitting approximately 131 tons of cadmium per year. The following description of the process of the municipal incinerator assumes that there is no resource recovery and that volume reduction is the prime motivation.

5.9.1.1 Process

First, the refuse is deposited in a receiving area which is essentially a pit up to 30 feet deep, 100 feet long, and 20 feet wide. From there, overhead cranes remove the refuse from the pit and deposit it in a feed hopper, which delivers refuse onto the combustion grates at a constant rate.

The most expensive part of the combustion plant, the grates, serve to transport refuse through the primary combustion chamber and simultaneously

insure that the maximum refuse surface is directly in contact with fire. Many types of grates are used to accomplish this; among the most popular are moving belts, reciprocating grates, and drum-type rollers.

The refuse is carried into the primary combustion chamber and is burned. Here, in a conventional refractory furnace, 150 to 200 percent excess air is supplied in order to prevent refractory materials from erosion by high temperatures. A result of this process is a large amount of exhaust gas production. This necessitates the use of a secondary chamber, in which the exhaust gases are subjected to additional combustion. The gaseous emissions are then discharged through the chimney stacks.

The resultant solid material, and all material which remains unburned, is deposited into a residue bin which empties directly into trucks. The trucks then carry the waste to a landfill.

5.9.1.2 Source of Emissions and Control

Emissions result from the combustion of plastics, paint pigments, and metal scrap which subsequently causes the volatilization of cadmium in the three items. Control devices most commonly used to combat the particulate emissions are wet scrubbers. Bag filters, or ESP's, are used occasionally. Approximately 83 percent of the total number of municipal incinerators use some sort of emission control, while 17 percent employ none.[1/]

5.9.1.3 Emissions Estimate

EEA's emissions estimate was based upon emission factors from source testing and the average rate of processing for a municipal incinerator. With the use of a scrubber or ESP, municipal incinerators release between 6×10^{-4} and 1.0×10^{-1} pounds of cadmium/ton of refuse.[5,7,8,10,14,33/] The results of a recent stack test using AA analysis were reported as $1.8 \pm 0.5 \times 10^{-2}$ pounds/ton.[5/] The earlier source testing (flame AA or

emission spectroscopy analyses) results were on the order of 10^{-3} or, more commonly, 10^{-4} pounds of cadmium/ton of refuse.[8,14,33/] Therefore, a best judgement factor of 1.3×10^{-2} pounds/ton of refuse was selected. This factor was based upon the mean of the recent test results minus the standard deviation in order to adjust for the lower results from previous stack tests using less accurate analyses. With a refuse figure of 20,143,620 tons[34/] and the best judgement emission factor, EEA estimates emissions to be 131 tons/year. EEA's emission estimate is higher than that of Davis (95 tons),[7/] Mitre (95 tons),[11/] EPA (48 tons),[2/] and Sargent (16 tons),[6/] but is in close agreement with that of GCA (150 tons).[2/] Because other estimates are fairly close to that made by EEA, one can surmise that the volume of municipal trash has increased since the others were made.

5.9.1.4 Future Trends

It is difficult to project future emissions resulting from municipal incineration. Control device use is expected to reach 100 percent before 1985. The number of municipal incinerators has decreased five percent annually over the last several years.[34/] However, those incinerators which have begun operation recently have capacities much greater than those which are closing. Therefore, existing capacity does not accurately reflect an increase or decrease in the number of municipal incinerators. Predictions call for 49 additional incinerators by 1979.[35/] As a result of the decreases in number, but increase in capacity, it is concluded that emissions through 1985 will remain constant. The effect of NSPS upon these new plants, and the use of high efficiency control devices by all municipal incinerators, should support the above assumption.

5.9.2 Sewage Sludge Incinerators

5.9.2.1 Process

The steps in the sewage sludge process differ in some ways from those in municipal incineration. First, the temperature of the feed sludge is raised to $212^{o}F$ to evaporate water from the sludge. The vaporization

and increase in temperature combine to raise the water vapor and air temperature of the gas, which in turn, serves to bring the volatiles of the sludge to ignition. End products are water, sulfur dioxide, carbon dioxide, and inert ash.

The multiple hearth is the most common incineration unit. A number of solid refractory hearths with a central rotating shaft are encompassed by a circular steel shell. "Rabble" arms, connected to the rotating shaft, serve to agitate the sludge which drops from one hearth to another through openings in each hearth. An inner cold air tube, which cools the rabble arms, runs through the central shaft. The shaft has an outer tube which serves a similar function for hot air. In this manner, continuous feeding can be accomplished.

5.9.2.2 Emissions Source and Control

As sludge is volatilized, cadmium is released into the air. Sewage sludge contains only a small amount of cadmium, originating from plastics or pigments, plus contaminants which may have become incorporated into the sludge from industrial or domestic wastewater. Until recently, it was possible to meet current emissions standards with the use of afterburners. However, present control of sewage sludge incineration emissions includes wet scrubbers.[1/]

5.9.2.3 Emission Estimate

Multiple hearth sewage sludge incinerators, controlled by scrubbers, are estimated by EPA to emit 7×10^{-6} pounds of cadmium/ton of dry sludge.[8/] EEA estimates that less than one ton results from incineration of 1,460,000 tons of sludge[36/] each year. This may be an underestimate, if the emission factor was developed based on emissions from an uncharacteristically well-controlled facility.

5.9.2.4 Future Trends

Sewage sludge production may increase to 1.5×10^6 tons/day[35/] by 1985, and assuming that 25 percent of this amount is incinerated,[36/] the emission of cadmium will increase along with the amount incinerated. However, several conditions temper this conclusion. The widespread application of control technology may decrease the rate at which cadmium emissions increase. On the other hand, recent bans on off-shore dumping and continually decreasing land-fill space may increase the amount of sludge incinerated. Because these factors will probably serve to counteract each other, EEA assumed that 25 percent of all sewage sludge would be incinerated, so that less than one ton of cadmium a year is expected to be emitted through 1985. This may be a conservative estimate, based on the assumption that the application of control technology will increase with the growing production of sludge. It is possible that some communities will find it too expensive to control sludge incineration, which would either aggravate the air pollution problem by emissions from poorly controlled facilities, or would result in land disposal of cadmium-bearing sludge.

5.10 SUMMARY

To determine the population affected by various concentrations of airborne cadmium, it was first necessary to determine sources of airborne emissions. Next, the specific part of each process from which emissions emanate was discerned and emission estimates were calculated. The emission estimates (Table 5-1) were based upon emission factors (Table 5-2) and production figures (Tables 5-1). Future emission estimates were also discussed (Table 5-1).

Airborne cadmium emissions derive from many sources, including: primary metal processes, production of items which contain cadmium (such as cadmium paint pigments), fossil fuel combustion, incineration, secondary metal processing, and the use of items which inadvertently contain cadmium (e.g., rubber tires).

Emission factors were obtained through an extensive search of current data sources. Minimum, Maximum, and "Best Judgement" figures were developed using methods and data reported below, and were tested in what is believed to be the order of decreasing accuracy:

- DATA: Stack tests usually conducted at only one location with multiple tests; samples analyzed by atomic absorption (AA) and results reported as cadmium emission factors or rates, or as cadmium concentrations in particulate matter and particulate emission rates or factors.

  METHOD: Emission factors for cadmium taken directly or calculated with reported or assumed values of process parameters (e.g., uncontrolled open hearth).

- DATA: Stack tests conducted at one or more location usually with one test per process; sampling train samples analyzed by emission spectroscopy, a semi-quantitative method, and reported as detected amounts or concentrations.

  METHOD: Emission factors calculated with reported particulate emission factors or rates as above (e.g., uncontrolled sinter windbox).

- DATA: Concentration of cadmium in particulate emissions, usually analyzed by emission spectroscopy (ES), but no particulate factors or rates reported (for a stack).

  METHOD: Cadmium emission factor calculated from the particulate emission factor or NSPS standard for the source type (e.g., maximum and best judgement factors for electric arc furnace).

- DATA: Concentration of cadmium in fuel or feed reported for for analysis by AA or ES.

  METHOD: Emission factor computed assuming 100 percent emission typical fuel characteristics (e.g., heating oil). Primarily used for liquid fuels.

- DATA: Survey of industrial plants or site visits conducted by EPA during development of original cadmium emission factors (e.g., minimum factor for cadmium processing).

METHOD: Mass balances for specific processes. Emission factor determined from unaccounted-for cadmium or by expected emissions for typical process and control equipment relative to total production or raw materials.

- DATA AND METHOD: Engineering estimates made when no other data is available (e.g., zinc roasting).

Table 5-1 provides a listing of emission factors which were used in the EEA study (1974). Production figures were obtained for use with emission factors to determine the emissions from each process (Table 5-2). A comparison of emission estimates, including those of EEA, can be seen in Table 5-3. EEA has estimated emissions assuming the same levels of control efficiency assumed in previous estimates (EEA 1974-1977 comparable), and assuming more accurate, current control technology (EEA Current Control). Estimates differ due to variability in production estimates, emission factors, and control technology assumption. Not all of the estimates in Table 5-3 consider the same sources of cadmium emissions; some estimates are more thorough than others. The total estimate for EEA's current control assumptions is one ton less than that shown in Tables 5-1 and 5-2, since the estimate of fertilizer emissions is not included (since no other estimate provided a comparison). Assuming the application of various control technologies by a percentage of operating facilities, yearly cadmium emissions total 849 tons. EEA's projections to 1985 indicate that total airborne cadmium emissions, assuming all facilities employ some type of control technology, will approximate 972 tons.

TABLE 5-1

AIRBORNE CADMIUM EMISSIONS--1974, 1985

Source	Production 1974*	Emissions Estimate	Reference**	Production 1985(e)	Emissions Estimate	Reference**
MINING						
Zinc	478,850	<1	12	845,377	<1	41
Copper	1,414,246.8	<1	12	2,563,122	<1	41
Lead	603,024	<1	12	1,169,524	<1	41
PRIMARY METALS						
Zinc						
Pyrometallurgic	423,000	529	40	1,000,000	529	9
Electrolytic	121,945	0	40	-	-	-
Lead	866,095	2	40	790,000	2	9
Copper	1,435,662.4	5	40	3,849,844	13	9
Cadmium	3,088.2	2	12	1,139	1	9
SECONDARY METAL PROCESSING						
Iron and Steel						
Sinter Windbox Uncontrolled	21.94×10^6	22	13	-	-	
Sinter Windbox w/Rotoclone and ESP	11.35×10^6	5	13	40×10^6	2-19	13
Basic Oxygen Furnace Uncontrolled	1.2×10^6	<1	13	-	-	
BOF w/Venturi or ESP	78.8×10^6	<1	13	116.7×10^6	1	13
Open Hearth Uncontrolled	7.64×10^6	22	13	-	-	
Open Hearth w/ESP	29.06×10^6	2	13	21.1×10^6	1	13
Electric Arc Controlled	27.3×10^6	5	13	39.8×10^6	7	13
Blast Furnace Controlled	95.2x10	0	13	113.6×10^6	0	13
Zinc	75,409	<1	47	130,000	1	47
Lead	698,698	<1	12	860,000	<1	9
Copper	513,308	38	12	800,000	60	20
MANUFACTURING						
Pigments	1,212.1	9	6	1,560	12	6
Stabilizers	991.8	3	6	1,179	4	6
Batteries	628.14	1	6	2,200	2	6
FOSSIL FUEL COMBUSTION						
Coal-Fired Power Plants	3.913×10^8	12	42	530.750×10^6	16	24
Oil-Fired Power Plants	500×10^6 (barrels)	9	42	732.2×10^6 (barrels)	14	46
Heating Oil	935.1×10^6 (barrels)	29 (1975)	45	980.9×10^6 (barrels)	31	46
Diesel Oil	11×10^9 (gallons)	4	39	15.12×10^9 (gallons)	5	38
Gasoline	$1,330,074 \times 10^6$ (VMT)	13	43	$1,707,152 \times 10^6$ (VMT)	17	44
MISCELLANEOUS						
Motor Oil	$1,028,121 \times 10^6$ (VMT)	1	43	$1,707,152 \times 10^6$ (VMT)	2	44
Rubber Tire Wear	$1,330,024 \times 10^6$ (VMT)	5	43	$1,707,152 \times 10^6$ (VMT)		44
Fungicides	59,800	<1	9	92,769	<1	9
Fertilizers	$8,535 \times 10^3$	<1	9	13,758	1	9
Cement	$81,210 \times 10^3$	<1	9	$94,737 \times 10^3$	<1	32
INCINERATION						
Sewage Sludge Incinerators	1,460,000	<1	36	1,551,250	<1	35,36
Municipal Incinerators	20,143,620	131	34	20,143,620	131	34
		850			877	

* tons per year unless otherwise stated.

e = estimated

VMT = vehicle miles traveled

** Reference refers to production

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TABLE 5-2

CADMIUM EMISSION FACTORS

SOURCE	MINIMUM	MAXIMUM	BEST JUDGEMENT	REFERENCES
PRIMARY METALS PROCESSING				
ZINC				
Coking	$1.96^{lb}/_{TZnThru}$ (EST,MB)	$2.48^{lb}/_{TZnThru}$ (STK,AA)	$2.24^{lb}/_{TZnThru}$	4,5
Sintering w/Cyclone	$4.06^{lb}/_{TZnThru}$ (STK,AA)	$8.58^{lb}/_{TZnThru}$ (STK,AA)	$6.32^{lb}/_{TZnThru}$ (STK,AA)	5
Sintering w/Cyclone & ESP	$2.10^{lb}/_{TZnThru}$ (STK,AA)	$2.22^{lb}/_{TZnThru}$ (STK,AA)	$2.16^{lb}/_{TZnThru}$ (STK,AA)	5
Roasting			~0 (EST)	6
Horizontal Retort	$1.2x10^{-21b}/_{TZnThru}$ (EST)	$8.7x10^{-21b}/_{TZnThru}$ (STK,AA)	$6x10^{-31b}/_{TZnProd}$ (EST)	6
Vertical Retort			$6.5x10^{-21b}/_{TZnThru}$ (STK,AA)	5,6
Electrothermic	$1.43^{lb}/_{TZnProd}$ (EST)	$2.96^{lb}/_{TZnProd}$ (STK,AA)	$1.2x10^{-21b}/_{TZnProd}$ (EST)	6
Overall (Not Electrolytic)			$2.5^{lb}/_{TZnProd}$	5,7,8
Electrolytic			~0	6
LEAD				
Overall Smelter	$5.2x10^{-21b}/_{TPbProd}$ (EST,MB)	$2.6x10^{-11b}/_{TPbProd}$ (EST,MAX CONC)	$1.1x10^{-11b}/_{TPbProd}$ (EST, AVE CONC)	2,7,8,10,11
Blast Furnace w/Baghouse			$5.25x10^{-31b}/_{TPb}$(STK,ES)	14
COPPER				
Uncontrolled Smelter	$7x10^{-21b}/_{TCu}$ (EST,MB)	$2.9x10^{-11b}/_{TCu}$ (EST,MB)	$1.5x10^{-11b}/_{TCu}$	2,7,8,10
Smelter w/Baghouse (~95%)			$7x10^{-31b}/_{TCu}$ (EST)	8
CADMIUM	$25^{lb}/_{TCdProd}$ (EST,SURV,MB)	$30.5^{lb}/_{TCdProd}$ (EST,MB)	$28^{lb}/_{TCd}$	7,8,10
SECONDARY METALS PROCESSING				
IRON & STEEL				
Sinter Windbox-Uncontrolled	$1.35x10^{-31b}/_{TFeed}$ (STK,ES)	$2.63x10^{-31b}/_{TFeed}$ (STK,ES)	$2x10^{-31b}/_{TFeed}$	14
Sinter Windbox w/Rotoclone & ESP	$9.33x10^{-41b}/_{TFeed}$ (STK,ES)	$9.76x10^{-41b}/_{TFeed}$ (STK,ES)	$9.5x10^{-41b}/_{TFeed}$	14
Blast Furnace-Controlled			~0 (EST)	51
Open Hearth-Uncontrolled	$4.08x10^{-31b}/_{TSteel}$ (STK,AA)	$6.48x10^{-31b}/_{TSteel}$ (STK,AA)	$5.78x10^{-31b}/_{TSteel}$ (STK,AA)	5
Open Hearth w/ESP	$2.08x10^{-51b}/_{TSteel}$ (EST,CONC)	$1.34x10^{-41b}/_{TSteel}$ (STK,AA)	$1.1x10^{-41b}/_{TSteel}$ (STK,AA)	5,11,12,15,17
Basic Oxygen Furnace				
Uncontrolled	$3.45x10^{-61b}/_{TSteel}$ (STK,ES)	$2.79x10^{-51b}/_{TSteel}$ (STK,ES)	$4.1x10^{-51b}/_{TSteel}$ (CONC)	15
w/Venturi or ESP	$2.7x10^{-31b}/_{TSteel}$ (EST,CONC)	$5x10^{-31b}/_{TSteel}$ (EST,STK,CONC)	$1.2x10^{-51b}/_{TSteel}$	14
Electric Arc Furnace			$3.4x10^{-31b}/_{TSteel}$ (EST,STK, CONC)	14,15
SECONDARY ZINC-UNCONTROLLED	$8x10^{-31b}/_{TZn}$ (SURV,MB)	$1.4x10^{-21b}/_{TZn\ Prod}$ (MB)	$1x10^{-21b}/_{TZn\ Prod}$	2,7,8,18,21
SECONDARY LEAD				7,10,18
Blast Furnace w/3 Cyclones & Baghouse	$5.9x10^{-71b}/_{TPb}$ (STK,ES)	$3.5x10^{-51b}/_{TPb}$ (STK,ES)	$2x10^{-61b}/_{TPb}$	14
Reverberatory Furnace w/ Cyclone & Baghouse	$5.9x10^{-71b}/_{TPb}$ (STK,ES)	$4x10^{-41b}/_{TPb}$ (STK,ES)	$1.6x10^{-61b}/_{TPb}$	7,14
Reverberatory Furnace w/ 3 Cyclones & Baghouse	$6.5x10^{-91b}/_{TPb}$ (STK,ES)	$2x10^{-41b}/_{TPb}$ (STK,ES)	$5x10^{-71b}/_{TPb}$	7,14
SECONDARY COPPER-UNCONTROLLED	$2.6^{lb}/_{TCu\ Scrap}$ (EST,MB)	$4^{lb}/_{TCu\ Scrap}$ (EST,MB)	$3^{lb}/_{TCu\ Scrap}$	7,8
MINING OF CADMIUM-BEARING ORES				
Zinc Ore			$2x10^{-11b}/_{TCd\ in\ Ore}$ (EST,MB)	5,2,7,21
Lead Ore			$1x10^{-31b}/_{TZn\ in\ Ore}$ (EST,MB)	2,3
Copper Ore			$1x10^{-41b}/_{TPb\ in\ Ore}$ (EST,MB)	2,3
MANUFACTURING			$3.2x10^{-51b}/_{TCu\ in\ Ore}$ (EST,MB)	2,3
Alloys & Solders-Controlled			$10^{lb}/_{TCd\ Charged}$ (SURV)	2,7
Pigments w/Baghouse			$15^{lb}/_{TCd\ Charged}$ (EST,MB)	2,7
Stabilizers (for Plastics) w/Baghouse			$6^{lb}/_{TCd\ Charged}$ (EST,SITE)	2,7
Batteries (Ni-Cd)			$2^{lb}/_{TCd\ Charged}$ (SURV)	2,7
Miscellaneous (X-Ray Screens, Cathode Ray Tubes, Nuclear Reactor Components,etc.)			$2^{lb}/_{TCd\ Charged}$ (EST)	2,7

TABLE 5-2 (continued)

CADMIUM EMISSION FACTORS

SOURCE	MINIMUM	MAXIMUM	BEST JUDGEMENT	REFERENCES
FOSSIL FUEL COMBUSTION				
Coal-Fired Power Plants				
Uncontrolled	$1x10^{-4}$ lb/TCoal (STK,AA)	$1x10^{-1}$ lb/TCoal (STK,ES)	$1x10^{-3}$ lb/TCoal	14,22,23
Controlled (ESP)	$1x10^{-6}$ lb/TCoal (STK,AA)	$7x10^{-4}$ lb/TCoal (STK,AA)	$6x10^{-5}$ lb/TCoal	7,8,10,15,21,31
Oil-Fired Power Plants				
Controlled (~ ESP)	$7.1x10^{-7}$ lb/gal (STK,ES)	$4.4x10^{-6}$ lb/gal (STK,CONC,ES)	$9x10^{-7}$ lb/gal (STK,ES)	14
Heating Oil (Residual; #6 Fuel Oil)	$1.5x10^{-6}$ lb/gal (EST,CONC)	$4x10^{-5}$ lb/gal (EST,CONC,NA)	$3x10^{-6}$ lb/gal	
Diesel Oil	$6x10^{-7}$ lb/gal (EST,CONC,ES)	$2x10^{-6}$ lb/gal (EST)	$7x10^{-7}$ lb/gal (EST,CONC,ES)	2,7,10,21,18,26,33
Gasoline (for 15 mpg, all Cd Emitted)	$6.3x10^{-11}$ lb/veh-mi (EST, CONC)	$4.5x10^{-8}$ lb/veh-mi (EST,CONC)	$2x10^{-8}$ lb/veh-mi	7,10,21,18
SEWAGE SLUDGE INCINERATORS				
Multiple Hearth w/Scrubber	$1x10^{-6}$ lb/TSludge (DRY)(STK, ES)	$2x10^{-5}$ lb/TSludge (DRY) (STK,ES)	$7x10^{-6}$ lb/TSludge (DRY) (STK, ES)	25,26,27,28,29
Fluidized Bed w/Scrubber	$4x10^{-7}$ lb/TSludge (DRY) (STK,ES)	$3x10^{-6}$ lb/TSludge (DRY)(STK,ES)	$1.3x10^{-6}$ lb/TSludge (DRY)(STK, ES)	7
MUNICIPAL INCINERATORS				7,14
Uncontrolled	$3x10^{-3}$ lb/TRefuse (EST)	$1.8x10^{-2}$ lb/TRefuse (STK,ES)	$6x10^{-3}$ lb/TRefuse (STK,ES)	
Controlled (Scrubbers or ESP)	$6x10^{-4}$ lb/TRefuse (FLAA)	$1.0x10^{-1}$ lb/TRefuse (EST,MB)	$1.3x10^{-2}$ lb/TRefuse (STK,AA)	7,14
LUBRICATING OIL INCINERATORS				5,7,8,10,14,33
Uncontrolled			$2x10^{-6}$ lb/gal (UNK)	7
MISCELLANEOUS				
Motor Oil Consumption (Vehicles)	$1x10^{-10}$ lb/veh-mi (EST,CONC)	$5x10^{-8}$ lb/veh-mi (EST,CONC)	$2x10^{-9}$ lb/veh-mi (UNK)	7,8
Rubber Tire Wear	$1.8x10^{-6}$ lb/gal (EST,MB)	$5x10^{-5}$ lb/gal (EST)	$8x10^{-9}$ lb/veh-mi	2,6,7,10
Fungicides Application	$1.7x10^{-4}$ lb/T (EST,MB)	$5x10^{-2}$ lb/T (EST,MB)	$1x10^{-5}$ lb/gal	7,8
Fertilizers Application			$6x10^{-3}$ lb/T	6,7,8,17,21,31
Superphosphate Fertilizers Application			$2x10^{-4}$ lb/T	6,7,31
CEMENT PLANTS				
DRY PROCESS				
Kiln w/Baghouse or ESP				
Raw Mill Feed w/Baghouse	$3x10^{-7}$ lb/TFeed (STK,ES)	$4.1x10^{-7}$ lb/TFeed (STK,ES)	$3x10^{-4}$ lb/TFeed (STK,ES)	7
Raw Mill w/Baghouse	$1x10^{-7}$ lb/TFeed (STK,ES)	$4.3x10^{-7}$ lb/TFeed (STK,ES)	$3.6x10^{-7}$ lb/TFeed	7,14
Raw Mill Air Separator w/ Baghouse	$7.6x10^{-7}$ lb/TFeed (STK,ES)	$9x10^{-7}$ lb/TFeed (STK,ES)	$2.7x10^{-7}$ lb/TFeed	7,14
Finish Mill Feed w/ Baghouse	$5x10^{-7}$ lb/TFeed (STK,ES)	$1.6x10^{-6}$ lb/TFeed (STK,ES)	$8.5x10^{-7}$ lb/TFeed	7,14
Finish Mill w/Baghouse		$1.3x10^{-7}$ lb/TFeed (STK,ES)	$1x10^{-6}$ lb/TFeed	7,14
Finish Mill Air Separator w/Baghouse			$1x10^{-7}$ lb/TFeed	14
WET PROCESS				
Kiln w/ESP	$7.4x10^{-6}$ lb/TFeed (STK,ES)	$2x10^{-4}$ lb/TFeed (STK,ES)	$2.6x10^{-6}$ lb/TFeed (STK,ES)	14
Raw Mill w/Baghouse			$2x10^{-5}$ lb/TFeed	7,14
Clinker Cooler w/ESP or Baghouse	$1.7x10^{-6}$ lb/TFeed (STK,ES)	$1x10^{-4}$ lb/TFeed (STK,ES)	$2x10^{-5}$ lb/TFeed	14
LIME KILN (PULVERIZED COAL)			$1x10^{-5}$ lb/TFeed	7,14
Kiln w/Spray, Settle & Baghouse	$4.6x10^{-5}$ lb/TFeed (STK,ES)	$6.9x10^{-5}$ lb/TFeed (STK,ES)	$5.7x10^{-5}$ lb/TFeed	14

a/ EST = Estimate; MB = Mass Balance; SITE = Site Visits; SURV = Survey of Companies; UNK = Unknown (in literature); STK = Stack Sampling Results; CONC = Concentration of Cd in feed, fuel, or emissions (w/STK); ES = Emission Spectroscopy; AA = Atomic Absorption (FL-Flame); NA = Neutron Activation Neutron Activation.

TABLE 5-3

COMPARISON OF CADMIUM EMISSION ESTIMATES 1968-1977
EMISSION ESTIMATES TONS/YEAR

Source	Davis 1968	ORNL 1968	MITRE	EPA 1971	GCA 1974	EPA 1975	EEA 1974-77 Comparable	EEA Current Control
Mining (Zn + Pb + Cu)	<1	<1	<1	<1	<1	<1	<1	<1
Primary Metals								
Zinc	-	-	619	644	500	102	529	529
Lead	1050	1050	55	163	65	-	48	2
Copper	-	-	388	234	110	-	108	5
Cadmium	-	-	-	60	50	-	-	2
Secondary Metals								
Steel Scrap	1000	<110	1000	78	400	10.5	146	56
Zinc	-	?	-	2	2	2.2	<1	<1
Copper	125	?	125	65	70		77	38
Lead	-		-	-	-	-	-	<1
Manufacturing								
Pigments	11	11	11	7	11	9.5	9	8
Stabilizers	3	3	3	4	3	2.7	3	3
Miscellaneous	<2	<2	<2	<1	<2	<1	<1	<1

TABLE 5-3

COMPARISON OF CADMIUM EMISSION ESTIMATES 1968-1977
EMISSION ESTIMATES TONS/YEAR (Continued)

Source	Davis 1968	ORNL 1968	MITRE	EPA 1971	GCA 1974	EPA 1975	EEA 1974-77 Comparable	w/ Est. Control[a]
Incineration								
Municipal	95	95	95	48	150	16	131	131
Sewage Sludge	-	-	-	138	12	20	<1	<1
Fossil Fuel Combustion	-	145-1100	-	198	250	130	75	67
Miscellaneous								
Motor Oil	1	1	-	-	<1	-	1	1
Rubber Tires	6	6	-	6	6	5.2	5	5
Forest & Agr. Burning	-	-	-	-	50	-	-	-
TOTAL =	2294	1425-2380	2305	1650	<1686	300	1176	849

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6. SCREENING OF CADMIUM SOURCE TYPES

6.1 INTRODUCTION

The ambient concentrations produced by the various sources of cadmium emissions were estimated very conservatively in order to determine which source types could potentially produce annual averages of cadmium greater than 0.1 ng/m^3 in the ambient air. It should be emphasized that this concentration was selected as significant for analysis only, since it implies nothing about possible health effects. The concentration is the lowest which can be consistently and accurately detected on an annual basis. Thus, the conservative preliminary screening of sources is designed to identify all possible cadmium emitters, which is not to say that all of these will be deemed significant from a health standpoint in subsequent analysis.

The average, "typical," and/or maximum plant capacity or production rates for each source type were collected from the industrial literature. For area sources, an area of emission was taken from the literature or estimated. For point sources, the stack characteristics, in terms of ranges or "typical" values, were compiled when available. The stack characteristics required were flow rate per production rate, stack temperature, and stack height. The primary references for this data were:

- Vandegrift, A.E., Shannon, L.J.; et.al., Handbook of Emissions, Effluents, and Control Practices for Stationary Particulate Pollutant Sources, Report for NAPCA Contract No. CPA-22-69-104, November 1970.
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Often little, if any, specific information was available for a given plant characteristic of a source type, so that an estimate had to be made. Such estimates were based on available information about the process, control equipment, and standard industrial practice.

The information on plant sizes, in terms of capacity of production rate, was extracted from the following sources:

- Deane, G.L.; Lynn, D.A., and Suprenant, N.F., Cadmium: Control Strategy Analysis, GCA-TR-75-36-G, Final Report for EPA Contract No. 68-02-1337, Task No. 2, April 1976.

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Most of the preliminary formation, such as industry production figures, and some detailed information, such as the size of units for primary smelting and some of the miscellaneous sources, were taken from the first reference. The remaining references were the sources of maximum or "typical" plant size information for mining and primary smelting, iron and steel plants, secondary smelting, manufacturing using cadmium, municipal incinerators, sewage sludge incinerators, and lubricating oil incinerators, respectively.

Fossil fuel consumption was estimated for a typical plant size, in the case of power plants, and derived from the following government publications for fuel oil and gasoline:

- "Sales of Fuel Oil and Kerosene in 1975," Mineral Industry Surveys, U.S. Department of Mines, Washington, D.C., 1976.

- National Functional System Mileage and Travel Summary from the 1976 National Highway Inventory and Performance Study, U.S. Department of Transportation, Federal Highway Administration, June 1977.

The first document gives fuel consumption by state for residual, distillate, and diesel fuel. The diesel fuel consumption is further broken down by on-highway and off-highway uses. The second report gives the density of vehicle miles traveled in the urbanized area for the major metropolitan areas and the states.

The compiled plant characteristics for the various source types were then used to make "realistic," but very conservative estimates of the effect of a "typical" or maximum size plant, for each plant type, on the concentration of cadmium in the ambient air. The effects of the area

sources were estimated for screening purposes by using the Hannah-Gifford urban air pollution model, assuming a very conservative (especially for an annual average) wind speed of two m/s, or the Miller Holzworth urban model for cities for which it had been calibrated. The effects of individual plants of the various point source types were estimated for screening purposes by using EPA's PTMAX dispersion model, using generally conservative emission rates, stack heights, temperatures, and flow rates. Using results from the PTMAX model is, conservative since the estimates from the model are maximum hourly ambient concentrations, while the ambient concentration of interest is the annual average. An annual average is generally a factor of three to four lower than a 24-hour average concentration, which is, in turn, generally a factor of three to four lower than an hourly average. In addition, the maximum concentration considered was the maximum for any wind speed and stability conditions. Thus, conditions which might occur for a short time, but which are unlikely to represent the annual average meteorological conditions, and which would occur very near to the plant, are often used to conservatively represent the worst realistic case. The emission rates (the products of the emission factors and production capacities or rates, expressed in grams per second) used were estimated assuming that a plant operated only 220 days per year and eight hours per day. Since most industrial facilities operate with a much higher capacity utilization, this greatly overstates the emission rate per hour. If available, both the maximum and a "typical" plant size were considered for both the maximum and best judgement estimates of cadmium emission factors in order to assess the likelihood of the estimated concentrations. For some source types, the two different estimates of plant size or of emission factors were nearly equal, so only the more conservative case was calculated. The stack characteristics for which PTMAX was run were generally chosen to be the representative for the plant type which would generate the highest predicted maximum ambient concentration for a given emission rate (of one g/s, i.e., low flow rate, low stack height, and

low stack temperature). The following sections briefly outline the estimated conditions and the results of the screening of the various cadmium source types. Due to the very conservative assumptions discussed above, a source which may appear to produce an hourly concentration greater than 0.1 ng/m^3 may be classified as a non-measurable source. The assumed stack and operating characteristics are sometimes so conservative as to produce an unrealistically high estimate of concentration. When this occurs for a particular source class it is noted in the text.

6.2 MINING

The cadmium concentrations resulting from the mining of cadmium-bearing ores were very conservatively estimated using the area source approach. For the largest zinc mine, it was assumed that the concentration of zinc in the ore was 2.6 percent and that the area of the mine was one square mile. For a wind speed of 2 m/s at these conditions, the Hannah-Gifford model estimates a concentration of 16 ng/m^3. However, the Hannah-Gifford model was developed for urban areas by assuming a series of line sources which is not the case for an isolated source such as mines. A wind speed of 5 m/s is generally more typical; the average mine produces 500,000 tons/ year, and a mine's property, if not its active area, is usually at least ten square miles. Therefore, it was presumed that a more realistic estimate of ambient concentration beyond the mine property would be at least two orders of magnitude lower and that even the largest mine would generate concentrations that were at most marginally greater than 0.1 ng/m^3. Since most zinc mines are underground mines, emissions would be expected to be much lower.

The analyses and conclusions were similar for the other types of mining which handle significant amounts of cadmium. The largest lead mine produces 1.6 million tons/year and the lead concentration in ore is estimated at 1.6 percent, so the ambient concentration for a one mile square area source would be 1.6 ng/m^3. Since most lead mines are underground

and the average production is only 350,000 tons/year, it is even more unlikely that measurable concentrations would be generated. Copper mines generally are surface mines producing as much as 19.6 million tons of ore per year. Assuming the maximum cadmium concentration in U.S. ores of 0.6 percent, and a rather conservative working area of ten square miles, an ambient concentration of 0.08 ng/m^3 is predicted. Obviously this level is insignificant for all other mine sizes.

6.3 PRIMARY METALS

The primary metal smelters were treated as point sources using very conservative plant and stack characteristics for screening purposes. The largest zinc smelter produces 250,000 tons/year, so this was used to calculate an emission rate for the various processes and the overall plant using the maximum emission factor. Assuming stack characteristics ranging from a 10 m stack emitting about 20 m^3/s at ambient temperature for coke ovens, to a 120 m stack emitting 235 m^3/s at 370 60 615°K for most of the processes, the range of estimated maximum concentrations ranged from 96 ng/m^3 to about 60 ng/m^3 for a horizontal retort and the overall process, respectively. Most of the individual processes would produce maximum ambient (hourly average) concentrations on the order of ten ng/m^3, so that even for an average plant size of 100,000 tons/year, it is unlikely that concentrations lower than the minimum detectable level (0.1 ng/m^3) would be produced. This is so even for the "best judgement" emission factors, as they are no more than a factor of two smaller than the maximum estimate emission factor.

Similarly, the largest primary lead smelter produces 350,000 tons/year. Therefore, assuming a 60 m stack with a flow rate of 160 m^3/s at 340°K for the overall smelter, and a flow rate of 4.8 m^3/s at 330°K for a baghouse controlled smelter, the ambient concentrations produced by the two model plants would be 8,700 ng/m^3 and 3,580 ng/m^3, respectively. Again, the average plant size is 52,000 tons/year and the "best judge-

ment" emission factor is less than a factor of three lower, so it is unlikely that concentrations less than 0.1 ng/m^3 would be produced. As the stack characteristics are similar for copper and cadmium smelters, with the production rates in the area of 200,000 tons/year the emission factors are at least as high, there is no question that these facilities also produce ambient concentrations far above the measurable level.

6.4 IRON AND STEEL

The individual iron and steel processes were screened using representative sizes for that process, while the overall plant was screened using the maximum production rate of three million tons of steel per year. All of the stacks were approximated as 40 m with temperatures of 310-340°K. The estimated concentrations range from 8.3 ng/m^3 for a 13,055 tons/day controlled basic oxygen furnace (using the "best judgement" emission factor and 95 m^3/s at 340°K), 450 ng/m^3 for a 6,504 tons/day uncontrolled open hearth (using the maximum emission factor and the same stack conditions). The overall plant estimate (using a flow rate of 220 m^3/s and 310°K) ranged from 16 ng/m^3 to 13 ng/m^3 using the maximum or best judgement emission factor. For the other processes (3,787 ton/day sinter strand, 1,440 ton/day blast furnace, and a 1,344 ton/day electric arc) the estimated concentrations were generally on the order of 100-1000 ng/m^3. Since the controlled estimates for the conservative screening technique were as low as ten's of nanograms per cubic meter, it was possible that some plants, particularly small ones, might prove to produce concentrations less than 0.1 ng/m^3. In the later analysis it was found that some plants did produce very low, but generally measurable concentrations, but that iron and steel plants with sinter strands, which are difficult to control efficiently, or with very large capacity, are estimated to produce maximum annual average concentrations on the order of hundreds of nanograms per cubic meter.

6.5 SECONDARY SMELTING

The uncontrolled emissions of secondary zinc and copper smelters were found to produce ambient cadmium levels greater than 0.1 ng/m^3, while

the controlled emission factors for secondary lead smelters were found to produce at most, barely measurable concentrations even for the conservative screening procedure. The 45,000 ton/year maximum size zinc plant, with an assumed stack of 40 m emitting 7.5 m^3/s at 340°K, would generate a maximum concentration of 900 ng/m^3. A secondary copper smelter producing 52 tons in a seven-hour-day and using a 20 m stack with a flow rate of 17.5 m^3/s at 370°K would generate concentrations which are another order of magnitude higher. Secondary lead plants, with a "typical" production rate of 2,500 lb/hr and high efficiency control equipment, were estimated to produce ambient concentrations less than 6 $ng/m^3/s$ at 340°K. Using the "best judgement" emission factors, the highest maximum concentration generated by PTMAX, even for these very conservative stack characteristics, was less than 6 ng/m^3. Therefore, since the range of sizes of secondary smelters is generally small, and the PTMAX estimates are hourly rather than annual averages, secondary lead smelters were eliminated from further consideration as detectable source of emissions.

6.6 MANUFACTURING

Very little information could be found about individual plants which manufacture products containing cadmium. Using the GCA estimates of the total production, the number of known plants, and the very conservative mass balance or survey estimates of emission factors, concentrations in the microgram per cubic meter range were estimated for very conservative stack conditions (20 m and 0.90 m^3/s at 340°K). Since there are probably many more smaller plants with increased control efficiency and larger stacks, it was concluded that the emissions of individual manufacturing plants are overestimated and would not produce measurable annual average concentrations of cadmium.

6.7 FOSSIL FUEL COMBUSTION

The only point sources considered that burns fossil fuel were power plants. Assuming a 300 MW(e) capacity (with ten million Btu/hr power MW(e) and 82 percent boiler efficiency, and a 130 m stack with a flow of 285 m^3/s at 440°K) an uncontrolled coal-fired power plant would produce ambient concentrations of 5 ng/m^3 with the "best judgement" emission factor and approximately 700 ng/m^3 with the maximum emission factor. Assuming a 60 m stack with a flow of 140 m^3/s at 440°K, the controlled coal- and oil-fired power plants were estimated to produce concentrations ranging from 0.8 ng/m^3 to 40 ng/m^3 for best judgement and maximum estimate emission factors. Thus, for more realistic conditions, some power plants were generally thought to produce concentrations somewhat greater than 0.1 ng/m^3. Therefore, an annual average CRSTER run (using Dallas/Fort Worth meteorological conditions and a very conservative 40 m stack with a flow of 105 m^3/s at 1,360°K) was used to determine the critical emission rate which could cause a maximum annual average ambient concentration greater than 0.1 ng/m^3 for each fuel type. The emission factors for each fuel type were then assumed to follow a log-normal distribution (with the probability of being exceeded at 90 percent for the minimum, 50 percent for the "best judgement," and ten percent for the maximum emission factor), and were multiplied by the capacities in the Energy Data System (EDS) file to calculate the emission rates for uncontrolled and controlled power plants (assuming a 24-hour operation). Plotting these emission rates on log-probability paper showed that only three plants had a greater than ten percent probability of exceeding the measurable ambient cadmium concentrations. These three plants were the three largest listed in the EDS with no control equipment. Since all power plants have some particulate control equipment (generally of greater than 90 percent efficiency), individual power plants were eliminated as detectable sources of cadmium.

The other fossil fuel combustion sources of heating oil, diesel oil, and gasoline were treated as area sources. For heating oil, the total amount of distillate (including off-highway diesel) and residual used in New York State in 1975 (the highest state consumption in the nation: 159 million barrels) was assumed to be burned in the urbanized area of Metropolitan New York City within New York State (1,634 mi^2) during a three-month period (24 hours per day). The ambient concentration, using the maximum emission factor and the Hannah-Gifford model with a wind speed of 2.0 m/s, was only 0.09 ng/m^3, so heating oil was eliminated as an individually-significant source. Similarly, the on-highway diesel fuel consumption of California (17.9 million barrels) was assumed to be used in Metropolitan Los Angeles (1,724 mi^2) over the entire year. Using the maximum emission factor, the concentration generated by the Hannah-Gifford model for a 2.0 m/s wind is 0.0012 ng/m^3. The Miller-Holzworth model for Los Angeles (city size 60 km) confirms this with a concentration of 0.00059 ng/m^3 for a mixing height of 300 m and one of 0.0031 ng/m^3 or a mixing height of 100 m and a wind speed of 1.0 m/s. The Miller-Holzworth model for Los Angeles was also used for gasoline consumption. The dai! · vehicle miles traveled per square mile (DVMT density) of 61.342 and an assumed mixing height of 300 m with a wind speed of 2.0 m/s generated an estimated 0.3 ng/m^3 for the maximum and 0.15 ng/m^3 for the "best judgement" emission factor. For the Washington, D.C., metropolitan area, the area with second highest DVMT density, the estimates are 0.17 ng/m^3 and 0.08 ng/m^3. Therefore, because of the accuracy of the estimates and the conservative meteorological assumptions for the areas with the most usage, gasoline consumption was concluded not to be an individually-measurable source of ambient cadmium.

6.8 MISCELLANEOUS

The miscellaneous sources of cadmium emissions are motor oil consumption, rubber tire wear, fungicides, and fertilizers. With the exception of fungicides, for which no information or application rates were

available and which may be banned in the near future, these sources were treated by the area source methodology. The same analysis was used for motor oil consumption and rubber tire wear as was used for gasoline (i.e., the Miller-Holzworth model using DVMT density). For motor oil consumption, the calculated ambient concentrations are 0.013 ng/m^3 for Los Angeles and 0.008 ng/m^3 for Washington, D.C. For rubber tire wear, the ambient concentrations are 0.04 ng/m^3 and 0.02 ng/m^3 using the "best judgement" emission factor for the two cities, respectively. Thus, the individual automotive sources of cadmium do not produce significant ambient levels of cadmium, even in the cities with the highest DVMT density. When a high fertilizer application rate of 20 g/m^2-year was assumed, the ambient concentration using the Hannah-Gifford urban area model with a wind speed of 2.0 m/s was calculated as 1.8 and 0.2 ng/m^3, with the maximum and "best judgement" emission factors, respectively. As the maximum emission factor assumes that all the cadmium in the fertilizer is emitted into the air, and a high fertilizer application rate and conservative dispersion model for rural locations was used, it was concluded that fertilizers would not produce greater than 0.1 ng/m^3.

Cement plants are another source of cadmium emissions that was found to produce very low ambient levels of cadmium when very conservatively modeled as a point source. Assuming the emissions from the entire cement production of the Lehigh Valley of Pennsylvania, 31 million lbs/year, came out of one stack (60 m with a flow of 115 m^3/s at 340°K), the maximum ambient (hourly average) concentration would only be 0.8 ng/m^3. With the same production rate, and even more conservative stack characteristics (as low as 20 m with a flow of 16 m^3/s and 290°K), only a few of the individual processes would produce hourly average concentrations above 0.1 ng/m^3. Therefore, for any individual cement plant, it was concluded that annual average ambient concentrations would be well below measurable levels.

6.9 INCINERATION

Municipal, sewage sludge, and lube oil incinerators, were screened as cadmium sources by using PTMAX and a point source treatment. For a municipal incineration with a 35 m stack, a flow of 9.4 m^3/s at 310°K, and the maximum or "best judgement" emission factor, the maximum and average capacities of 1,600 and 300 tons per 24-hour day are estimated to generate ambient concentrations on the order of micrograms per cubic meter. Since the control equipment on incinerators is generally not of high efficiency, municipal incinerators were considered to produce measurable annual concentrations of cadmium.

The maximum capacity sewage sludge incinerator of 7.5 tons per hour, which operates only three days a week, would generate an ambient concentration of less than 3.0 ng/m^3 (maximum hour) even for a 20 m stack with a flow of 2.5 m^3/s at 310°K. With a 35 m stack and the same flow rate the maximum hourly average concentration is 1.7 ng/m^3 for the controlled multiple hearth maximum emission factor for the same process (0.12 ng/m^3 for the controlled fluidized bed). It was therefore concluded that with more realistic assumptions the annual average emissions would not produce average ambient concentrations of cadmium greater than 0.1 ng/m^3.

The only information that was available on lubricating oil incinerators was that the total amount incinerated by a multitude of small sources was estimated to be 389 million gallons per year. Assuming that the uncontrolled emissions from incinerating all the lubricating oil in the nation came out of a 20 m stack with a flow rate of 0.9 m^3/s at 340°K, an hourly ambient concentration on the order of micrograms per cubic meter is estimated by PTMAX. Since there are probably thousands of such incinerators in the country, it is presumed that the annual average ambient cadmium concentrations generated by any one of them would be below measurable levels.

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